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English-language Soviet manual entitled MIG-21F-13 Aircraft Flying Technique Manual, consisting of 265 pages [redacted] The purpose of this manual is to aid the pilot in achieving the correct flying technique for this aircraft as well as to assist instructors in establishing correct procedures of pilot training.

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MIG-21F-13 AIRCRAFT FLYING TECHNIQUE Manual

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Chapter I

GENERAL INFORMATION ON MiG-21 -13 AIRCRAFT

The MiG-21 -13 aircraft is a one-seat supersonic jet fighter possessing high performance abilities.

As to its configuration the aircraft is an all metal cantilever midwing monoplane equipped with delta wing and sweepback empennage with controllable stabilizer.

Design features of the MiG-21 -13 aircraft as compared with the preceding types of fighters are as follows:

(a) thin delta wing (thickness chord ratio is 4.3 per cent) with low aspect ratio (2.2);

(b) comparatively narrow landing-gear tread (2.6 m.) as installation of a thin wing has necessitated retraction of the main landing gear into the fuselage;

(c) supersonic air intake (with pointed inlet edges), to ensure reliable operation of the air intake at high supersonic speeds, the former has mechanical devices installed in it (telescopic cone, antisurge shutters);

(d) "take-off shutters" designed for decreasing losses in the duct at low flying speeds (particularly at take-off);

(e) wing flaps of floating type for take-off and landing.

Three air brakes installed on the aircraft are to improve maneuverability of the latter. The lateral air brakes are conceived to serve also as gun mounting hatch doors.

To cut down landing roll the aircraft is equipped with a brake chute, its maximum permissible ejection speed being 280 km/hr.

The aircraft has the following detachable parts:

(a) fuselage nose section;

(b) fuselage tail section;

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(c) two outer panels;
(d) two sections of stabilizer;
(e) ailerons;
(f) three air brakes;
(g) landing flaps;
(h) rudder;
(i) fin tip assembly;
(j) cockpit canopy;
(k) landing gears;
(l) main wheel and nose wheel well doors;
(m) main Pitot-static tube.

Construction joints of the MiG-21 -1 aircraft are shown in Fig.1.

Dimensions of Aircraft

Length	12.26 m.
Wing area	23 sq.m.
Wing span	7.15 m.
Leading edge sweep	57°
Stabilizer area	3.94 sq.m.
Stabilizer deflection angles, up	13 ±1°
Stabilizer deflection angles, down	28 ±1°
Vertical empennage area	3.3 sq.m.
Fin sweep	60°
Rudder area	0.965 sq.m.
Rudder deflection angles	±25°
Wing flaps area	1.87 sq.m.
Wing flaps deflection angle	26°
Ailerons area	0.88 sq.m.
Ailerons deflection angles (up and down)	20 -1°
Air brakes area (total)	1.3 sq.m.
Centre-of-gravity limitations	31.5 - 36 per cent MAC

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Weight of Aircraft

Gross take-off weight without drop tank ... 7110 kg (at γ_{fuel} = = 0.83 gr/cu.cm.)

Gross take-off weight with drop tank of 490-lit. capacity ..... 7560 kg (at γ_{fuel} = = 0.83 gr/cu.cm.)

The МиГ-21Ф-13 aircraft armament consists of two special missiles K-13 equipped with infrared homing device, of НР-30 cannon (starboard) and two rocket pods УБ-16-57 for unguided rocket missiles. The aircraft has the АСП-5ИД sight coupled with the ОПС-5Б infrared sight.

This armament ensures engagement of air targets in the daytime and at night in good weather conditions and above clouds within all operational ranges of speeds and altitudes of flying of the МиГ-21Ф-13 aircraft.

Aircraft Power Plant

The aircraft is equipped with a two-shaft turbojet Р-11Ф-300 engine (Fig.2), consisting of the following principal parts:

(a) axial-flow six-stage two-rotor compressor;

(b) ten annular type combustion chambers mounted in common casing;

(c) two-stage axial-flow gas turbine[x] ;

(d) afterburner with two-position exhaust nozzle;

(e) fuel supply and engine automatic control systems;

(f) self-contained lubrication system;

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x/ Turbine first stage rotates compressor high-pressure rotor (H.P.R.), while its second stage actuates low-pressure rotor (L.P.R.).

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(r) automatic starting system incorporating [illegible] generator-starter.

Principally, operation of two-shaft engine does not differ from that of one-shaft engine.

The distinguishing feature of the two-shaft (or two-rotor) [illegible] engine is that its axial-flow compressor is divided into two independent groups of stages (two cascades), each group of stages being driven by a separate turbine. Thus, the group of the first three stages which constitute the low-pressure compressor is driven by the second (in the direction of gas flow) turbine, that is by the low-pressure turbine, while the next three stages forming high-pressure compressor are driven by the first turbine, that is by the high-pressure turbine.

Low-pressure compressor and turbine make up a low-pressure rotor (L.P.R.), and high-pressure compressor and turbine - a high-pressure rotor (H.P.R.). There is only gas dynamic relationship between these two rotors.

The main advantage of the two-shaft engine is high stability of compressor operation in non-rated conditions.

The rated conditions of compressor operation imply the conditions which ensure minimum losses of power used for compression of the air, that is, which allow attaining maximum efficiency while the air compression process is not accompanied by blade flow separation effect.

The rated conditions of compressor operation are attained at quite definite for each individual engine values of r.p.m., altitude, flying speed and ambient temperature. In case of considerable fluctuations of the above-mentioned values around the rated ones, the compressor experiences sharp variations of axial speeds of air flow entailing flow separation which initiates intensive vibration of the blades and leads to unstable operation (surge) of the compressor. And the higher is the compression ratio, the narrower will be the range of stable operation of the compressor, i.e., at smaller

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fluctuations of the values around the rated ones the compressor experiences surge. It is advantageous, therefore, to compress air in several successive compressors having low compression ratio (up to 3 - 4) and wider range of stable operation.

Stable operation of the two-shaft P-11F-300 engine, having compression ratio 8.6, is ensured at all ratings without installation of additional mechanical devices in the compressor.

Variations of engine operating conditions (flying speed, altitude, ambient temperature, engine control lever position) entail changes of air flow axial speeds in the stages of the compressor. In two-shaft engine it leads to redistribution of aerodynamic loads on both cascades (torques required for rotation of the cascades undergo changes; they increase on one cascade and decrease on the other) and as a result of that r.p.m. ratio of the rotors changes automatically.

Self-adjusting of r.p.m. of the rotors results in stable operation of both cascades, when changes in axial speeds of air flow in the compressor duct at various ratings (as to r.p.m.) take place.

This mainly explains the advantages of the two-shaft turbojet engine.

The principle of the P-11F-300 adjustment consists in maintaining constant r.p.m. of the low-pressure rotor at all altitudes and flying speeds.

R.p.m. of the high-pressure rotor, which is not connected mechanically with the low-pressure rotor, change according to altitude and flying speed variations, i.e., depending on the temperature of the engine inlet air.

Thus, when flying speed and, consequently, engine inlet air temperature increase, the high-pressure rotor r.p.m. increase too, and vice versa.

Climbing to 11,000 m. altitude at constant flying speed causes high-pressure rotor r.p.m. drop but at altitudes exceeding 11,000 m. high-pressure rotor r.p.m. remain unchanged as the air temperature is constant.

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After the high-pressure rotor maximum permissible (as to structural limitations) r.p.m., equal to 103.[illegible] per cent, are reached, further build-up in flying speed does not lead to their increase, while at the same time low-pressure rotor r.p.m. will drop as a result of the [illegible]-21 pump automatic device action.

Afterburning fuel supply is adjusted according to the principle of maintaining constant ratio of air pressure after compressor and of gas pressure after turbine at all flying speeds and altitudes.

With increase of flying speed the air pressure after compressor grows, therefore, to maintain the above mentioned pressure ratio constant, the [illegible]-22 pump regulator will allow more fuel into afterburner and the gas pressure after turbine will increase.

Engine main characteristics are given in Table 1.

Table 1

Power setting	Thrust, kg	R.P.M. per cent		Specific fuel consumption, kg/kg thrust-hr	Air consumption, kg/sec	Turbine exhaust gas temperature, °C
		Low-pressure rotor	High-pressure rotor			
Full augmented	5750	100	100	2.3	63.7	Not exceed. 700
Maximum	3900	100	100	0.94	63.7	Not exceed. 700
Nominal	3100	93	95	0.89	59	550
Idle rating	Not exceed. 700	30	48	460	-	Not exceed. 420

The [illegible]-21-1[illegible] aircraft is equipped with a supersonic air intake and two-position adjustable inner cone. The cone which

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is actuated by a special hydraulic unit is automatically fixed in the following positions:

Position number	M-number	Cone position
I	From 0 to 1.5	Retracted
II	From 1.5 to 1.9	In first forward position
III	Above 1.9	In extreme forward position

Timely adjustment of the cone in a corresponding position is performed automatically on M-relay signal. In case of the automatic device failure the cone can be controlled by a manual switch installed in the cockpit.

The purpose of cone extension, when M-number is increasing, is to forestall unstable operation, i.e., surge of air intake and cut down losses in it to the minimum. As is known, the surge of the air intake is most likely at high M-number, i.e., when the amount of air passing through aircraft air duct exceeds the amount of air the engine is capable to consume. In view of this, all those factors that tend to increase the amount of air flowing through the duct (gusts of wind, cone extension delay and others) as well as those causing reduction of air consumption by the engine (r.p.m. drop) assist in occurrence of air intake surge.

Besides, at high M-number air intake surge may occur due to air flow disturbance in the duct as in case of sharp change of angle of attack when the air flow is entering the duct at a certain angle. To forestall this effect the air duct entrance is equipped with automatically operated shutters which eliminate possibility of air intake surge by bleeding some air from the duct.

These shutters open automatically in two cases:

(a) at M-numbers exceeding 1.5 when the aircraft control stick is pulled rearward to a position which causes stabilizer leading edge deflection by 20° with the APY automatic trans-

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nozzle ratio control unit being in the "large area position" irrespective of engine control lever position;

(b) at Mach 1.5 when the engine is throttled down to 98 per cent of maximum r.p.m. and less (at M-numbers equal to or exceeding 1.5 throttling the engine down to r.p.m. less than 97 per cent are not allowed). In case of shutters automatic control failure the shutters will be actuated by the switch installed in the cockpit.

The aircraft air duct has also rear shutters installed in it which are conceived to increase the thrust at take-off by supplying additional air to the engine. These shutters are not provided with positive control system and operate on the effect of the differential of pressure inside and outside the duct. The shutters open inward when the engine is run on the ground and also at take-off and in flight when the air duct experiences rarefaction. Increase of speed and, consequently, of impact pressure leads to pressure build up in the duct and to closure of the shutters.

Aircraft power plant is displayed in Fig.3. The J-11,-3 engine having thrust variable at augmented rating allows the thrust to be controlled within engine power setting ranges from MINIMUM AUGMENTED (MIN. AFTERBURNER) position to the FULL AUGMENTED (FULL AFTERBURNER) position. This enhances manoeuvrability of the fighter when flying in combat formations at supersonic speeds.

At the [illegible] RATING ([illegible]) [illegible] UP I ([illegible]) and MAXIM. ([illegible]) settings the shutters will be closed, their position coinciding with the nozzle diameter - $52^{+1.0}$ mm. At MINIMUM AUGMENTED power setting the nozzle diameter enlarges to $61^{+1.0}$ mm and at FULL AUGMENTED power setting - to $67^{-1.0}$ mm.

Low-pressure rotor r.p.m. at power settings within MINIMUM AUGMENTED - FULL AUGMENTED limits remain constant while the temperature of gases when afterburner is throttled

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down increases by 15 - 25°C. High pressure rotor r.p.m. increase by 1 - 1.5 per cent.

Basic operating power settings of the engine are given in Table 2.

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Table 2

Power setting	Low-pressure rotor r.p.m., per cent	Turbine exhaust gas temperature, °C	Oil pressure, kg/sq.cm.	Duration of continuous operation
1	2	3	4	5
Full augmented	100 during cut-in and cut-off; overrun - not exceeding 106.5 momentarily (not more than 5 sec.)	Not exceeding 700, when above 90 sec. - not more than 720	3.5 - 4	On the ground - not more than 15 sec.; in flight up to 10,000 m. - not more than 10 min., above 10,000 m. - not more than 20 min.
Minimum augmented	100	Same	Same	Same
Maximum	100 during cut-in and cut-off; overrun - not exceeding 106.5 momentarily	Same	Same	On the ground - not more than 1 min.; in flight up to 10,000 m. - not more than 10 min.; above 10,000 m. - not more than 20 min.

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1	2	3	4	5
Nominal	93	Not limited	3.5 - 4	Not limited
0.8 of nominal Idle rating	88 R.p.m. are adjusted on the ground according to ambient temperature	Same Not exceeding 420	Same Not less than 1	Same On the ground - not more than 10 min.; in flight is not limited
Engine starting	-	Not exceeding 560	-	Time limit of engine picking up IDLE RATING after GROUND STARTING button is pushed must not exceed 60 sec. or 80 sec. when internal power is used for starting

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Engine accelerating ability. When checking accelerating ability of the engine advance engine control lever during 1.5 - 2 sec.

Time to accelerate the engine from idle speed r.p.m.: 90 per cent r.p.m. - 9 - 10 sec.;

to augmented rating (full, minimum and intermediate) - not more than 20 sec.

Time to accelerate the engine from 65 to 90 per cent - r.p.m. - 7 - 10 sec.

Time to accelerate the engine from full rated power to augmented rating (full, minimum and intermediate) - not more than 2 sec.

Notes: (a) Time limit for engine operation within 95 - 100 per cent r.p.m. range is the same as for full rated power setting operation.

(b) Repeated setting of power exceeding 95 per cent is allowed only after cooling the engine at normal rated power or lower power settings during not less than 1 min.

(c) When flying at altitudes above 10,000 m., oil pressure is allowed to drop to 3 kg/sq.cm.

(d) Maximum allowed r.p.m. of high-pressure rotor - 103.5 per cent.

(e) Low-pressure rotor r.p.m. overrun during afterburner cut-in and cut-off and during acceleration should not exceed 106.5 per cent. Duration of overruns - not more than 5 sec.

(f) After engine starting, ignition system plugs will be checked at idle speed during 30 sec.

Engine operation at full thrust power setting. When climbing under certain rate of climb conditions with the engine operating at full thrust power turbine exhaust gas temperature will drop. At 10,000 m. turbine exhaust gas temperature must not be below 550°C.

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Turbine exhaust gas temperature drop is accompanied by reduction of high-pressure rotor r.p.m. by about 3 per cent as a result of ambient temperature decrease.

Engine operation at augmented rating. FULL AUGMENTED rating is reliably set at altitudes not exceeding 16,000 m. and IAS not lower than 450 km/hr; at higher altitudes minimum speed for full augmented power setting increases reaching 600 km/hr at 19,000 m. (time for cutting-in - up to 4 sec.).

While setting augmented power it is necessary to check illumination of the AUGMENTED (O.C.S) signal light, both rotors' r.p.m. and turbine exhaust gas temperature; the latter's drop during augmented power setting in flight may reach 90°C.

When augmented power is being set, high-pressure rotor r.p.m. are also dropping though the limit of the drop is not specified.

Augmented power setting is performed smoothly, without jerks and without off-limit turbine gas temperature rise.

In case augmented power setting is accompanied by surge or turbine exhaust gas temperature increase above the permissible limit it is necessary to cut-off afterburner by retarding the engine control lever to the FULL AUGMENTED position.

If after locking the engine control lever at the detent FULL AUGMENTED the afterburning power does not cut-off, it is necessary to use AFTERBURNER switch.

Close watch for r.p.m. of both rotors and turbine exhaust gas temperature should be maintained during engine operation at afterburning power and during acceleration of the aircraft. During acceleration high-pressure rotor r.p.m. increase.

Maximum permissible r.p.m. of high-pressure rotor are 103.5 per cent, maximum permissible turbine exhaust gas temperature - 700°C.

If high-pressure rotor r.p.m. increase beyond 103.5 per cent limit or turbine exhaust gas temperature rises above

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[illegible] acceleration will be diminished and [illegible] and [illegible] [illegible] r.p.m.

During the high-pressure rotor reaches 1[illegible] - 1[illegible] 5 [illegible] r.p.m. and acceleration continues, the low-pressure rotor [illegible] experience r.p.m. drop.

High-pressure rotor r.p.m. reach their maximum value [illegible] low-number close to critical.

Power lower than full rated one may be met only after turbine exhaust gas temperature drops to 5[illegible]° (with still higher temperature present).

[illegible] engine is operating at [illegible] power, [illegible] fuel pressure will be lower than in the case [illegible] operation at full augmented power; besides, burning [illegible] is less stable in the former case than in the latter. [illegible] conditions this factor can lead to pulsation [illegible] (high altitudes and low IAS).

[illegible] maximum afterburning unstable operation speeds are [illegible]:

[illegible] ..... [illegible] km/hr IAS
[illegible] ..... [illegible] km/hr IAS
[illegible] ..... [illegible] km/hr IAS

[illegible] limited from afterburner the engine employment [illegible] unstable burning, it is necessary to advance engine [illegible] lever to full augmented position and for flying [illegible] need power to increase IAS or decrease altitude.

Aircraft Fuel System

The aircraft fuel system ensures engine fuel supply at all altitudes and operating ratings.

Fuel system consists of:

(a) six fuel tanks located in fuselage and two wing fuel cells, additional drop tank can be suspended under the fuselage;

(b) fuel drain system and fuel tank supercharging system;

(c) engine fuel-supply system;

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(d) engine starting fuel system.

Fuel system simplified block diagram is given in Fig.4.

Drop tank capacity is 490 lit.

Flexible fuselage tanks are locked in containers and are divided into three groups (each of them having its own pump):

(a) first group - tank No.1 and top section of tank No.2 (fuel transfer pump No.1 is installed in tank No.1);

(b) second group (fuel supply) - tank No.3 and bottom section of tank No.2 (fuel pump No.2 is installed in tank No.3);

(c) third group - tanks Nos 4, 5, 6 (fuel transfer pump No.3 is installed in tank No.4).

Root cells of the right and left wings serve as wing tanks.

Drain system and tanks supercharging system

To improve altitude characteristics of system the fuel tanks are supercharged with air taken from engine compressor.

In case when velocity head exceeds supercharging by air taken from compressor (during diving) the tanks will be supercharged by means of velocity head via special intake.

Supercharging value is 0.21 - 0.23 kg/sq.cm.

Engine fuel service system

From tank No.3 the fuel is delivered to the engine by the fuel pump (495A assembly).

The fuel transfer pump (422A assembly) transfers the fuel from the first group of tanks into tank No.3.

From tank No.2 bottom section the fuel free flows into the fuel service tank, while from tanks Nos 5 and 6 it free flows into tank No.4 and then is transferred into tank No.3 by means of the fuel transfer pump (422A assembly).

Under excess pressure effect the fuel is transferred from wing cells into fuel service tank No.3.

The fuel contained in the drop tank is sent to bottom section of tank No.2 under the effect of engine air pressure

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(0.6 kg/sq.cm.) delivered by the compressor, and from tank No.1 free flows into tank No.3.

The corresponding signal lights installed on the pilot's instrument panel illuminate to indicate that all fuel from the first and second groups of tanks and from the drop tank is used.

Besides, the system is provided with signal lights indicating reserve fuel left (about 500 lit.).

To ensure engine fuel supply during an inverted flight, the lower part of tank No.3 is designed as inverted flight cell.

The fuel is used in the following sequence: firstly, about 30 lit. are used from tanks Nos 1, 2 and 3, then entire total quantity of the drop tank, further follows simultaneous consumption from the wing cells and third group tanks.

The fuel is delivered from tanks Nos 1 and 2 and fuel service tank after it has been completely consumed from the third group of tanks.

The signal lights in the cockpit should illuminate in accordance with fuel consumption sequence: DROP TANK CONSUMPTION (DROP TANK EMPTY), fuel remainder signal light - 500 lit. FUEL REMAINDER (500 L).

The sequence of fuel consumption is automatically controlled.

Engine Starting Petrol System and Starting Igniter Oxygen Supply System

The petrol system is designed to deliver petrol to the starting igniters during engine starting on the ground and in flight.

The petrol system incorporates:

(a) 4-lit. capacity petrol tank supercharged by air directed from the compressor;

(b) fuel pump;

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(c) electromagnetic valve which opens during engine starting and by-passes petrol to the igniters.

To render engine starting in flight more reliable the aircraft is equipped with independent starting igniter oxygen supply system.

Engine starting, if oxygen feed is available, is ensured at altitudes up to 12,000 m., while without the latter reliable starting can be accomplished at 6000 m. and below.

After the circuit breaker IN FLIGHT [illegible] (BA[illegible] BO[illegible]) is switched on, oxygen from the bottle is sent to the igniters via oxygen reducer, decreasing pressure to 9 - 10.5 kg/sq.cm., and to electropneumatic valve.

Available oxygen allows five cycles of starting of 30 sec. each. The pilot checks availability of oxygen pressure gauge installed in the cockpit (pressure must be within 9 - 10.5 kg/sq.cm. limits).

Oxygen is not supplied to the igniters when the button ENGINE STARTING (BA[illegible]) is pushed during engine starting on the ground.

Engine Control System

The engine is controlled by the engine control lever installed in the cockpit left subpanel.

Via rigid rods and bell cranks the engine control lever is connected with the power setting control panel (of [illegible]-1 type) installed on the engine.

The engine control lever can be locked in positions CUT-OFF, MAXIM. and AUGMENTED while traveling forward and in positions AUGMENTED, IDLE RATING and CUT-OFF when being retarded.

In position NOMINAL the engine control lever is locked with a ball. To unlock the engine control lever it is necessary to press corresponding handles.

A special detent responding to (MP-1.5) M-number transmitter signals is installed to ward off aircraft air duct

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surge when the engine is throttled down at high speeds. This detent prevents retarding of the engine control lever to the position corresponding 97 per cent r.p.m. when flying at M-number exceeding 1.5.

In case of the detent mechanism failure or when it becomes absolutely necessary to throttle the engine down at M-number exceeding 1.5, the pilot can remove the detent by pushing a special button installed at the rear of the engine control lever.

Hydraulic and Pneumatic System 3

The MiG-21Ф-13 aircraft has two independent hydraulic systems: a servo system and a main (landing gear) system.

The feeding diagram of assemblies controlled by the hydraulic system is given in Fig.5.

Operating fluid used in the system is [illegible].

Fluid quantity in both systems - 35 lit.

To improve altitude characteristics of the system, hydraulic fluid compression is resorted to. For this purpose the air under pressure of 1.7 - 2.2 kg/sq.cm. is sent from the compressor to the hydraulic fluid tanks.

The servo (booster) system provides for operation of a booster chamber of the stabilizer booster BV-[illegible] and two aileron boosters BV-45.

The main system is designed for retracting and extending the landing gears, wing flaps, air brakes, air intake cone, for operation of the air intake antisurge shutters, for controlling engine jet nozzle shutters and for automatic braking cylinder supply.

Emergency extension of the landing gears is accomplished by means of the pneumatic system. Other assemblies operating on the main hydraulic system are not provided with emergency control.

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Besides, the main system provides for operation of the second chamber of the stabilizer booster [illegible]-51 and for operation of the [illegible]-45 boosters in case the servo system pressure drops to 70 kg/sq.cm.

Variable displacement pumps, type [illegible]-34 (one in each system), mounted on the engine are conceived as pressure generating sources.

Besides, the servo system is provided with an emergency pumping unit [illegible]-27 driven by an electric motor designed to facilitate landing with engine cut-off, when both [illegible]-34 pumps fail (hydraulic system piping is operative).

Maximum operating pressure of the hydraulic fluid in both hydraulic systems is 210 kg/sq.cm. Normal operating pressure is 210 - 160 kg/sq.cm.

Operation of the hydraulic systems is checked by two-pointer pressure gauge and yellow signal lights installed on the instrument panel.

The lights illuminate when pressure drops below 165 kg/sq. cm. and go off when it rises above 195 kg/sq.cm.

All hydraulic system assemblies are set into operation by means of remote electrohydraulic cocks controlled from the cockpit.

The hydraulic systems ensure operation of the [illegible]-51 and [illegible]-45 boosters in the following order:

(a) when both hydraulic systems are normally operative:

1. One chamber of the stabilizer booster [illegible]-51 operates on the servo system, the other chamber - on the main system.

2. Aileron boosters [illegible]-45 operate on the servo system;

(b) when servo system pressure drops to zero (manifold rupture, [illegible]-34 pump failure) and the main system is operative:

1. In stabilizer booster [illegible]-51 only one chamber is active, the one operating on the main system.

2. Aileron boosters [illegible]-45 operate on the main system;

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(c) when main system pressure drops to zero (manifold rupture, [illegible] pump failure) and the servo system is operative:

1. Only one booster operating on the servo system is active in the [illegible] booster assembly.

2. Aileron boosters [illegible] operate on the servo system;

(d) servo system pressure drop below 165 kg/sq.cm. ([illegible] pump failure) initiates automatic cutting-in of the [illegible] pumping) unit and illuminates the servo system failure signal light; with the [illegible] pumping unit on and hydraulic system piping intact, servo system pressure will be maintained at 180^{+5} kg/sq.cm. level (the system failure signal light will be always on).

The [illegible] pumping unit operation is checked by the servo system pressure gauge (the pressure must be within 180 - 165 kg/sq.cm. limits).

Operating from the cockpit the pilot can cut off aileron hydraulic boosters simultaneously from the main and servo systems.

When main system pressure drops to 130 kg/sq.cm. all main system consumers (landing gears, flaps, air brakes, etc.), except jet nozzle shutters, hydraulic boosters of ailerons and stabilizer, are automatically disconnected from the system.

The aircraft main pneumatic system is employed for wheel braking, operation and pressurization of the canopy, emergency jettisoning, reloading of the armament, operation of the fuel cut-off valve, ejection and jettison of the brake chute and operation of the de-icing system.

The emergency pneumatic system is designed for landing gear emergency extension and main wheels emergency braking.

Main and emergency system bottles maximum pressure is 110 - 130 kg/sq.cm.

The key diagram of supply of assemblies operating on the pneumatic system is given in Fig.6.

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Take-Off and Landing Devices and Airfoil Mechanical Arrangement

The MiG-21F-13 aircraft is equipped with a tricycle landing gear.

The main struts are of telescopic type and are provided with nitrogen-fluid shock absorbers.

The nose wheel strut is of knee lever type and is also equipped with a nitrogen-fluid shock absorber. Landing gear retraction and extension are performed by means of the hydraulic system. The landing gear cock is operated via the lever installed on the left side of the instrument panel.

In emergency the landing gear is extended by means of the pneumatic system. The landing gear emergency extension cock is installed on the right subpanel. There is also an independent system of nose wheel mechanical extension.

In retracted position the main landing gear struts are housed in the wing and the wheels - in special fuselage wells.

The nose wheel strut is retracted into the fuselage nose section well.

The main landing gear struts rest on wheel assemblies, 660x200, incorporating disc brakes (unit KT-82).

Wheel tyre operating inflation pressure is 9 kg/sq.cm. at normal take-off weight and 10 kg/sq.cm. at maximum take-off weight.

The nose wheel strut rests on brake wheel assembly, 500x180 (unit KT-38). Nose wheel tyre operating inflation pressure is 6 kg/sq.cm.

The aircraft is provided with an automatic anti-skid arrangement. If any of the main wheels experiences skid, the brakes of the landing gear including the nose wheel are automatically released. In case of the nose wheel skid the main wheels remain braked.

The emergency braking system is applicable only to the main wheels. Emergency air is sent directly to the brakes.

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[illegible] cut down landing roll the aircraft is equipped with a brake chute housed in the left underside of the [illegible] tail section.

Ejection and jettisoning of the brake chute are accomplished by means of the electrical power [illegible].

To improve aircraft maneuverability during taxiing the nose wheel is provided with a steering mechanism.

The wing of the aircraft is equipped with "slotting" flaps to improve take-off and landing characteristics of the plane.

In extended position the flaps are held only by hydraulic system fluid pressure and if the increased [illegible] kg/cm², the flaps will retract completely pushing the fluid out of the cylinder into the pressure line.

Take-off and landing flaps deflection angles are the same and equal to 26°.

Aircraft Control System

The aircraft flight controls are shown in Fig. 7.

The ailerons are controlled by the pilot's control stick via rigid kinematic connection consisting of rods and bell cranks.

For overcoming aerodynamic load affecting the ailerons the system of aileron control is provided with two "V-" boosters connected in irreversible circuit and operating on the servo and main hydraulic systems.

With the operating aileron boosters, the load experienced by the control stick during its deflection is originated only by the spring loaded mechanism. If the aileron boosters are deflected, the load on the stick during its deflection increases due to the necessity to overcome aerodynamic load and rod friction.

Two mechanisms of control stick-to-ailerons transmission ratio nonlinear variation are installed before the aileron booster. The monitoring transmission mechanism facilitates aileron control during small deflection of the stick from the neutral

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position, when the boosters are inoperative and ensures satisfactory lateral controllability of the aircraft at high speeds with the operating boosters.

As displayed in Fig.8 small deflection of the stick from the neutral position causes small deflection of the ailerons. The aileron nonlinear deflection mechanism decreases aircraft lateral control efficiency at those flying conditions where efficiency of the ailerons was excessive when nonlinear mechanisms were not available.

At high M-numbers as well as at low flying speeds efficiency of the ailerons decreases; this necessitates considerably greater deflections of the stick which in their turn cause greater deflections of the ailerons.

The stabilizer is controlled (Fig.9) by means of the control stick via the two-chamber MV-11 booster connected in irreversible circuit. The MV-11 booster is operating on the servo and main hydraulic systems simultaneously.

The stabilizer control system incorporates the AY-5 automatic transmission ratio control unit which automatically changes control stick-to-stabilizer transmission ratio and control stick-to-spring loaded mechanism simultaneously depending on IAS and altitude.

The spring loaded mechanism is designed to create loads on the control stick when the latter is deflected from its neutral position.

The load imparted to the control stick by the spring loaded mechanism is proportional to deflection of the stick from its neutral position and to position of the AY-5 unit which depends on IAS and altitude.

The system incorporates also a "trimming effect" mechanism conceived to balance the aircraft in flight longitudinally according to the efforts applied to the stick.

The "trimming effect" mechanism control pressure switch is installed on the control stick.

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The APV-3B automatic transmission ratio control unit is designed to change control stick-to-stabilizer and control stick-to-spring loaded mechanism transmission ratio.

With the APV-3B automatic unit operating, the control stick travel length (between extreme positions) remains unchanged while stabilizer deflection range and stick load value change considerably.

When flying at subsonic ratings, IAS build up increases stabilizer efficiency and the latter may become excessively high if control stick-to-stabilizer and control stick-to-spring loaded mechanism transmission ratio remains constant.

With IAS increase the stabilizer controls must be made heavier in operation to maintain normal controllability of the aircraft at altitudes below 10,000 m. This is done by the APV-3B automatic transmission ratio control unit.

Responding to IAS build up at altitudes below 10,000 m., the APV-3B unit changes control stick-to-stabilizer transmission ratio (i.e., a certain travel of the stick causes smaller deflection of the stabilizer than would be expected) and increases the load on the stick emanating from the spring mechanism (i.e., forces on the stick increase though the stick travel value remains the same).

The APV-3B unit adjustment according to velocity head takes place within 450^{+60}_{-30} - 1010^{+10}_{-20} km/hr IAS range.

When the aircraft develops supersonic speed, its longitudinal stability increases intensively while stabilizer efficiency somewhat deteriorates. Consequently, when the aircraft reaches supersonic speeds, it is necessary to discontinue coarsening of the controls to avoid deterioration of aircraft maneuverability. This function is performed by correction mechanism which controls switching-on of the APV-3B automatic unit depending on flying altitude.

Each altitude within 5000 - 10,000 m. range has quite definite IAS corresponding to it which is close to speed of

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sound and beginning from which further IAS growth will necessitate discontinuance of stabilizer control coarsening.

The range of altitudes for switching-on of the АРУ-3В unit correction mechanism is 5000 - 10,000 m.

The АРУ-3В unit operation in flight is checked on the АРУ-3В unit indicator and by the Т-4 light panel signal light.

The rudder is controlled by the pedals from the cockpit. It is connected with the pedals by means of rigid rod system. The aircraft controls are not equipped with aerodynamic trim tabs.

Pressurized Cockpit

The МиГ-21Ф-13 aircraft has a pressurized cockpit of ventilation type.

Prior to pressurizing the cockpit it is necessary to close the canopy by operating the canopy control handle. The canopy moves down after the handle has been turned vertically to rest against the detent STOP. Then the handle is advanced full forward to lock the canopy. After the canopy locks are engaged (which is indicated by jutting out of the lateral lock pins), the canopy is sealed (the pressuring hose is filled with air) by pressing a special pressurization handle. The canopy pressurization and control system diagram is given in Fig.10.

The cockpit is supercharged with air supplied by the engine compressor. The АРД-57В automatic pressure regulator maintains a given air pressure in the cockpit. The regulator cock installed on the cockpit starboard must always remain in position ON and locked.

With the supercharging system operating normally, the pressure differential starts to grow from 2000 m., reaches its maximum value 0.29 - 0.31 kg/sq.cm. at 9000 - 12,000 m. and at higher altitudes remains constant. The cockpit pressure is checked by the УВПД-20 indicator. To deliver air into the

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cockpit it is necessary to open the COCKPIT SUPPLY ([illegible] KAP[illegible]) cock installed on the right panel.

A given cockpit temperature is automatically maintained constant. When COCKPIT HEATING ([illegible]) switch is in position AUTOMATIC ([illegible]), the air delivered by the engine is divided into two streams by the electrical distributing cock.

Part of the air enters the air-heat exchanger and turbo cooler for cooling, and the other part (hot air) flows direct into the cockpit. Prior to entering the cockpit the flows are mixed.

The ratio of hot and cool air entering the cockpit is controlled automatically depending on the cockpit temperature.

In case of automatic arrangement failure the pilot can regulate the cockpit temperature manually. For this purpose the COCKPIT HEATING switch is turned to positions either COOL AIR or HOT AIR depending on the cockpit temperature. When the switch is turned neutral, the distributing cock will cut off the air flow and its shutters will stop in the position they reached at the moment of cut-off.

The cockpit supercharging system is displayed in Fig.11.

Aircraft Emergency Abandonment Equipment

The MiG-21-15 is provided with CK ejection seat.

The CK ejection seat with canopy protection has the following advantages as compared to a seat provided with a curtain:

(a) in the process of ejection it protects the pilot effectively against air flow; this allows to increase the range of safe ejection speed to 1000 km/hr IAS;

(b) it considerably shortens the time required for cockpit preparation for ejection from the moment when decision to abandon the aircraft is made to the moment, when the initial position is taken and handholds (grips) are pressed; the pilot

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is not obliged to specially rearrange his position before ejection, he should only press the handholds;

the seat is provided with the system which automatically changes the pilot's position prior to ejection;

(c) after ejection the pilot is separated from the seat more energetically which allows to decrease minimum permissible safe height of ejection to 110 m.

Bail out from the MiG-21F-13 aircraft can be performed either by ejecting under canopy protection or by ejecting with preliminary jettison of the canopy.

Fire Protection Equipment

The aircraft is provided with fire protection system designed to extinguish fire in the engine location area.

Two-lit. capacity bottle contains fire extinguishing agent 7 which is used as fire quenching liquid. The header-distributor is installed in fuselage in the engine front section.

The fire detector warning system consists of two heat-proof metal tubes (ionization warning units) arranged in semi-circle at the fuselage fitting frame.

The noteworthy feature of the MG-2 fire detector warning system operation as compared with ordinary thermocouples consists in the fact that the thermocouples send fire warning signal only after they have detected flames and do not respond to temperature rise. When flames between the aircraft body and fire warning unit are detected, the light signal FIRE illuminates on the T-6 light panel.

To operate the fire extinguishing system it is necessary to push the FIRE EXTINGUISHER (ОГНЕТУШИТЕЛЬ) button installed on the cockpit left panel. This will fire the explosive charge and set the extinguisher into operation.

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De-Icing System

The MiG-21F-13 aircraft de-icing system is designed to remove ice from the canopy windshield. Ethyl alcohol is used to wash the ice off the windshield. To operate the system it is necessary to switch on the FIRE EXTINGUISHING EQUIPMENT, CANOPY DE-ICER FUEL SHUT-OFF COCK (ПОЖАР, ЗАЩИТА ДВИГАТЕЛЯ, ЛЕВ.ПОЖ) circuit breaker located on cockpit port and press the CANOPY DE-ICER (ПРОТИВООБЛЕДЕНИТЕЛЬ ФОНАРЯ) button installed on the instrument panel left subpanel.

When the button is pressed, the electric circuit of the ЭК-48 valve closes and the air delivered by the aircraft pneumatic system is sent to 6.5-lit. capacity alcohol reservoir. The air pressure pushes the alcohol out of the tank and sends it to the header installed on the canopy. The system will cut off when the button is released.

The alcohol is used most effectively when the system is switched on for a period of 2 - 3 sec. Successive switchings of the system after short intervals will be necessary if one period of operation fails to remove ice.

The system capacity allows 20 - 30 switchings of 2 - 3 sec each.

Aircraft Equipment

The aircraft equipment is designed to facilitate flying in good and bad weather conditions in the daytime and at night.

It consists of flight and navigational instruments, electrical equipment, lighting and signal light equipment, radio communication, radio navigation and radar equipment.

Aircraft Electrical Equipment

The aircraft electrical equipment consists of power generating sources and electrical circuits of direct and alternating currents, as well as of power consumers. The D.C. power supply

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consists of the ГСР-СП12000БТ generator-starter and two storage batteries connected in parallel. Connection of the generator to and disconnection from the aircraft mains are accomplished by means of the GENERATOR (ГЕНЕРАТОР) switch installed on the front right-hand electrical panel.

The BATTERY, EXTERNAL POWER master switch is used to connect the storage battery and the external power supply to and disconnect from the aircraft mains. The master switch is fitted on the cockpit front right-hand electrical panel.

Aircraft mains voltage is checked by the voltmeter installed on the right-hand instrument subpanel. Aircraft mains voltage must be 28 - 29 V with the generator operating and 22 - 23 V when only the batteries are on. Disconnection of the generator from the aircraft mains is indicated also by illumination of the GENERATOR OFF red signal light located on the T-6 light panel.

External power supply is connected to the aircraft mains through the external power receptacle and via a special cable and the КПА-2 adapter box.

To preserve capacity of the aircraft batteries at low temperatures of outside air, the latters are provided with electrically heated jackets.

The batteries are heated from the external power supply when the BATTERY HEATING (ОБОГ АККУМУЛЯТОРА) switch, installed on the cockpit right-hand horizontal panel, is ON.

A.C. power supply consists of the following inverters.

1. Two ПО-750А inverters converting D.C. of the aircraft mains into single phase A.C. 115 V, 400 c.p.s. One ПО-750А inverter supplies power to the РСИУ-5Т radio set, the АРК-10 radio compass, the СРО-1 aircraft transponder, the РМС-16А-4 fuel flow meter, the АКМ-8Т remote-inducting pressure gauge and МС-2 ionization fire warning unit. The second ПО-750А inverter supplies the АСП-5М1 sight, the СРД-5М radio-range finder and СИБ-52 infrared sight.

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In case of the first inverter failure, the [illegible], АРК-10, СРО-1, [illegible], РТС-16А-4 and [illegible]-2 can be operated on the power supplied from the second inverter, which is manually switched on by closing the INVERTER EMERGENCY SWITCH ([illegible].) circuit breaker, installed on the cockpit front right-hand electrical panel. At the same time the [illegible], [illegible], [illegible]-2 will automatically cut off. Instead of the [illegible] remote-inducting pressure gauge the [illegible] pressure gauge, operating on D.C., is provisionally installed in the aircraft. The [illegible] pressure gauge is supplied with power via the GENERATOR SIGNAL OIL PRESSURE [illegible] (С [illegible] ВУП, КЛС) circuit breaker.

2. The [illegible]-500А inverter designed to supply the [illegible]-У low-altitude radio altimeter and [illegible]-5 [illegible] marker receiver unit with alternating voltage of 115 V, 400 c.p.s.

<u>Notes</u>: 1. Temporarily until the [illegible]-500А inverter is installed in the aircraft, the [illegible]-У and [illegible] will be operating on power supplied by the second ПО-750А inverter. These consumers will also cut off when the INVERTER EMERGENCY SWITCH ([illegible].) circuit breaker is closed.

2. The aircraft design of later series provides for emergency power supply of the [illegible]-У and ЭРП-56П in case of the generator or ПО-500А inverter failure.

By closing the [illegible]-У, ЭРП EMERGENCY SUPPLY (АВАРИЙН.ПИТАНИЕ РБ-У, ЭРП) circuit breaker, the above said consumers are connected to the first ПО-750А inverter. At the same time the СРО-1 aircraft transponder will be automatically disconnected from this inverter.

3. The [illegible]-70 inverter designed to supply power to the ГИК-1 gyro induction compass and ВК-53РБ erecting cutout.

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4. The ПАГ-15 inverter designed to supply power to the АГД-1 artificial horizon (ПАГ-15 and ПТ-70 convert D.C. of aircraft mains into three phase A.C. 36 V, 400 c.p.s.). The inverters are switched on by closing circuit breakers or by turning on the corresponding consumer switches fitted on the cockpit electrical panels. The aircraft is not provided with A.C. source operation check and signal arrangements.

Aircraft Utility Lighting

The utility lighting equipment incorporates:

(a) two ultraviolet light lamps in the АУФОЛ-45 fittings, mounted on the control stick and on the cockpit port; the ultraviolet light lamps are supplied with power via the АУФОЛ, EXTENSION LAMP, HEATING OF ИКО-3 (АУФОЛ,НЕ [illegible] ЛАМПА, [illegible] ИК-3) circuit breaker installed on the cockpit rear right-hand electrical panel and protected with a plexiglas cover; the ultraviolet lights are controlled by ULTRA-VIOL. LAMP, LEFT and U.V.L. ON CONTROL STICK rheostats, mounted on the cockpit, starboard;

(b) white light lamp in the КАСИК-45 fittings installed on the cockpit starboard; the lamp is supplied with power via the КАС, ЗУК, GENERATOR SIGNAL OIL PRESSURE circuit breaker, fitted on the left electrical panel; the lamp is switched on and adjusted as to intensity by the rheostat;

(c) the АФСБ-45 landing light mounted on the left wing underside at the fuselage; power is supplied to the landing light by closing the LANDING LIGHTS, LANDING GEAR EXTERNAL INDICATING LIGHT (ФАРЫ,ВЫП.ШАС.,ЛАСС) circuit breaker (installed on the front right-hand electrical panel); the landing light is controlled by the switch mounted on the left fixed instrument subpanel; when the switch is turned from position OFF to position ON, the landing light extends and illuminates;

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(d) the [illegible]-1[illegible] taxiing light installed on the nose wheel strut; it is energized and controlled via the same circuit breaker and switch which are used for the landing light (when the switch is turned to position TAXIING LIGHT ([illegible]) the taxiing light illuminates).

Aircraft Signal Light Equipment

The signal light equipment consists of:

(a) [illegible]-45 and XC-39 navigation lights supplied with power via L.G. WARNING, NAVIGATION LIGHTS ([illegible]) circuit breaker installed on the rear right-hand electrical panel and protected with a plexiglas cover; [illegible] intensity (100, 50, 10 per cent) is adjusted by the [illegible] mounted on the cockpit port;

(b) two T-4 and T-6 warning light panels indicating normal (green shielded) and emergency (red shielded) conditions of operation of various systems; panel lights operation is checked by special CHECK (КОНТРОЛЬ) push-buttons. With power on, the T-4 and T-6 light panel lamps are checked by turning on the TRIM EFFECT MECHANISM (ТРИМ.-Э СЖТ) switch (for T-4) located on the front right-hand electrical panel and closing the [illegible] GAUGE OF HYDRAULIC SYSTEM, FUEL [illegible], DROP AND SERVICE TANK WARNING SYSTEM ([illegible]) circuit breaker (for T-6) located on the left-hand electrical panel; special shields which can be set in two positions: DAYTIME ([illegible]) and NIGHT (НОЧЬ) are installed to regulate intensity of T-4 and T-6 light panel lamps;

(c) the [illegible]-2 flight and landing signal unit; with power on, the lights of the unit are checked by the LAMP TEST (КОНТРОЛЬ [illegible]) push-button when the L.G. WARNING NAVIGATION LIGHTS circuit breaker, located on the rear right-hand electrical panel under a plexiglas cover, is closed; at night, intensity of the landing gear extended and retracted position signal

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lights can be decreased by setting a special shield on the ПНС-2 unit panel to position NIGHT (НОЧЬ);

(d) the flap control Щ3-1 panel; at night, intensity of the flap position signal lights will be decreased by setting a special shield of the Щ3-1 panel to position NIGHT (НОЧЬ);

(e) signal lights in the СЖ-51 fittings with various shields indicating position or condition of aircraft systems; the fittings provide for decreasing intensity of the lights at night by turning the shield clockwise;

(f) landing gear down position signal lights;

(g) utility and signal light arrangements on the panels of the attached units АРК-10, СРО-1, sight, etc.).

Aircraft Radio Communication Equipment

The radio communication equipment consists of a VHF communication radio set РСИУ-5Р. The radio set operates in 100 - 150 Mc frequency range and ensures two-way voice communication in flight at six pre-set channels with push-button control; it does not need additional search and frequency tuning. Channel change-over is accomplished in less than 4 sec. after the button is pressed.

The radio set is energized by closing the RADIO (РАДИО) circuit breaker located on the front right-hand electrical panel. Closing of the circuit breaker starts the ПО-750А inverter and supplies all the necessary voltages for radio set operation.

After 1 - 2 min. (required for tubes warming) the radio set is ready for operation. Radio set TRANSMITTING (ПЕРЕДАЧА) duty is provided by pressing the button on the engine control lever. The radio control panel mounted on the aircraft port side provides for channel selection, volume control, initiation of radio interference suppressor as well as for selection of the telephones for radio set and radio compass monitoring. The УК-2М amplifier is installed on the left-hand control panel

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to facilitate communication when throat microphones or lip microphones (as in the ГШ-4М pressurized helmet) are used. When the pilot is flying with the helmet on, the switches on the УК-2М amplifier must be: one - in the КГ position, the other - in the Н position (both up); when the ГШ-4М pressurized helmet is used, the first switch must be in the ГШ position, the second in the Н position (both down).

Aircraft Radio Navigation Equipment

The radio navigation equipment and ILS equipment incorporate the АРК-10 radio compass, РВ-У low altitude radio altimeter and МРМ-5 М marker receiver unit.

The АРК-10 automatic radio compass is designed for navigation of the aircraft by utilizing NDB's and broadcasting stations and for instrument landing with the help of instrument landing system. Besides, the radio compass can be used as HF radio receiver.

Aircraft Radar Equipment

The radar equipment includes the СРО-1 aircraft transponder and СРД-5К radio-range finder.

The СРО-1 aircraft transponder is an airborne component of the radar identification system, which sends corresponding coded signals on request of aircraft and ground transmitters. If it is necessary to identify his aircraft on radar scopes, the pilot must turn on the DISTRESS (БЕДСТВИЕ) switch, fitted on the transponder control panel and protected with a green clip.

Power is supplied to the transponder via the TRANSPONDER (ОТВЕТЧИК) circuit breaker located on the rear right-hand electrical panel under a plexiglas cover and via the POWER-OFF (ПИТАНИЕ-ВЫКЛЮЧЕНО) duplex switch on the СРО-1 transponder

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control panel. Transponder operation is controlled and checked through the control panel mounted on the cockpit starboard.

Structural Features of MiG-21F-13 Aircraft Equipped with АФА-39 Camera Installation

The camera equipment of the MiG-21F-13 aircraft is designed for carrying out preplanned aerial photography of individual objectives, routes and small areas: from altitudes up to 5000 m. - for detailed aerial photo reconnaissance and from altitudes above 5000 m. - for surveillance photo reconnaissance.

The АФА-39 camera is installed on the hatch door in the starboard detachable section of the wing between ribs 1 and 2.

The camera doors open automatically by means of a spring mechanism when landing gear right leg fairing door pin (when full up) presses the camera hatch door double-arm lever. The doors close also automatically by means of the spring mechanism when landing gears are being extended. The camera doors are open when the aircraft flies with gears up.

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Chapter II

MiG-21F-13 AIRCRAFT AERODYNAMIC ARRANGEMENT AND FLIGHT CHARACTERISTICS

Aircraft Aerodynamic Arrangement

The MiG-21F-13 aircraft aerodynamic arrangement concept was to attain minimum possible drag and good stability and controllability.

The aircraft has a low aspect ratio thin delta wing, fairly long fuselage provided with a specially designed for supersonic speeds engine air intake and sweepback empennage with a controllable stabilizer. The most advantageous midwing configuration was employed for wing-to-fuselage connection.

This aerodynamic arrangement resulted in relatively low drag and, consequently, in aircraft high performance abilities. The tendency of aircraft C_{D_0} drag coefficient change is displayed in Fig.12, which indicates that C_{D_0} drag coefficient rise, as a result of wave drag, starts at M = 0.9, reaches its maximum value at M = 1.1; and at M-numbers above 1.1 drag coefficient smoothly decreases. The wave drag augments aircraft drag coefficient at M = 1.1 twice as compared with the drag at low M-numbers.

Origination and development of wave stagnation at transonic and supersonic speeds lead to sharp and considerable change of all aerodynamic characteristics of the aircraft. Drag sharp rise necessitates considerable augmentation of engine thrust to enable the aircraft to fly at transonic and supersonic speeds.

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Abrupt variations of C_L and C_m coefficients and displacement of centre of pressure considerably disturb stability and controllability of the aircraft.

All these factors necessitate reduction and smoothing of drag stagnation effect on the aircraft aerodynamic characteristics by changing aircraft configuration. For this purpose profile configuration and airfoil plan form as well as fuselage configuration are changed.

In subsonic aircraft profiles of thickness chord ratio equal to 12 - 15 per cent and higher, in case they possessed considerable relative camber, were mainly employed.

Transition to transonic and particularly to supersonic flying speeds has demanded employment of low thickness/chord ratio and small relative chamber profiles and even symmetrical profiles, as they enabled to reduce drag considerably. Besides, in case of wave stagnation, C_L and C_m coefficients of thin symmetrical airfoils change more smoothly which results in lesser changes of aircraft stability and controllability. Therefore, while in subsonic aircraft airfoils had usually only asymmetrical profiles, the airfoil of the МиГ-21Ф-13 aircraft has only symmetrical profiles.

The other way to reduce wave stagnation effect on aircraft aerodynamic characteristics is the change of airfoil plan form, i.e., employment of sweepback wings, low aspect ratio wings and lastly, decision to use delta wings which combine the above mentioned properties and at the same time make it possible to apply thin profiles.

If we compare aerodynamic characteristics of rectangular, sweepback and delta wings, we shall find out that at low speeds sufficiently high aspect ratio rectangular wing possesses better characteristics. It has the highest angle of attack C_L coefficient curve slope value, highest aerodynamic property and the lowest induction drag at high C_L coefficients.

Characteristics of the sweepback wing at low speeds are considerably worse. At constant angle of attack its lift de-

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creases when sweepback angle increases, and at high C_L coefficients the drag augments rapidly as a result of flow separation at the wing tips.

Characteristics of the low aspect ratio delta wing are still worse. Its sole advantage - great $C_{L_{max.}}$ coefficient value though in these cases angles of attack become so great that it is practically impossible to use high $C_{L_{max.}}$ coefficients at landing.

The picture is changed when speed increases to M-number close to 1. At these M-numbers great sweepback considerably reduces the drag and improves characteristics of longitudinal stability and controllability. Therefore, transition from transonic speeds to supersonic ones demands wing sweepback angle increase usually up to 60° approximately.

In this case negative characteristics of wing sweepback at low speeds (premature tip flow separations, deteriorated conditions of flap operation, etc.) manifest ever stronger and strength characteristics deteriorate considerably. Further reinforcement of sweepback wings entails great increase of the wing weight and makes application of this wing very problematic.

The above mentioned drawbacks brought about the conception of the low aspect ratio delta wing which is more advantageous at supersonic speeds. This configuration of the wing possessing sufficient construction rigidity and great load-carrying capacity (the last mentioned property is very important for fighter aircraft) combines ability of the sweepback wing to delay wave stagnation (up to M-number 0.9 - 0.95) and possibility to use profiles of very low thickness chord ratio (3 - 6 per cent) for sharp reduction of wave drag at supersonic speeds.

In addition, the delta wing has better stability characteristics and contributes to improvement of aircraft controllability.

We shall briefly discuss the effect of the delta wing on longitudinal stability and controllability of the aircraft at

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transonic and supersonic flying speeds. It is known that aircraft longitudinal stability and controllability depend upon the location of the aircraft C.G. and its aerodynamic centre. Aircraft aerodynamic centre position is determined mainly by wing aerodynamic centre.

At low (subsonic) flying speeds the aerodynamic centre of a rectangular wing is, approximately, at one quarter of its MAC counting from wing nose section. With M-number increase the aerodynamic centre advances somewhat forward at first and then at M = 1 rapidly shifts to a distance of 50 per cent of the wing chord.

Sharp aerodynamic centre variations at wave stagnation speeds and its considerable displacement rearward at supersonic speeds fairly disturb controllability of the aircraft equipped with a rectangular wing and, in smaller degree, controllability of the sweepback wing aircraft.

In case of a delta wing, with M-number increase the aerodynamic centre displaces within smaller range and more smoothly. This factor provides better longitudinal stability and controllability of the aircraft.

Aileron effectiveness of the delta wing aircraft is considerably higher than that of the sweepback wing aircraft, which is partially accounted for by greater rigidity of the delta wing.

The delta wing has also an adventage over the sweepback wing at low IAS. It is a fact, that at low IAS, due to the effect of boundary layer shifting from the middle to the tips of the wing, the sweepback wing experiences flow separation at the outer wing. This leads to sharp deterioration of lateral stability and controllability, to considerable loss of aileron effectiveness in particular, that aggravates flying of the aircraft at low IAS and especially landing of the aircraft. Besides, flow separation at the wing tips, located behind the aircraft C.G., deteriorates also longitudinal stability and controllability of the aircraft by provoking big pitching

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moments and forward displacement of the aerodynamic centre.

The desire to improve sweepback wing operation at low IAS necessitates installation of high $C_{L_{max}}$ coefficient profiles at wing tips, fore flaps or aerodynamic fences.

The delta wing does not require the above said modifications as at these speeds the delta wing is streamlined somewhat differently.

In case of the delta wing, secondary speeds originate in the boundary layer on the wing upper surface in the plane perpendicular to the main flow. On the larger part of the wing the secondary speeds at the wall and at the outside limit of the boundary layer have opposite directions as is displayed in Fig.13 for the starboard wing.

Maximum values of the secondary speeds will be at the leading edge. These secondary speeds shape the boundary layer into three-dimensional vortex flow, as is shown in Fig.14. With the increase of angles of attack, boundary layer vorticity augments and is transferred into the main flow; this leads to formation of trailing vortices above the wing upper surface, as displayed in Fig.15. Vortex intensity rises when the angle of attack increases. Vortex formation prevents flow separation at the wing tips and leads to considerable flow thinning on the outer wing upper surfaces. Fig.16 shows the tendency of flow thinning variations along the delta wing span depending on angle of attack. As is shown in Fig.16, at low angles of attack flow thinning is little changed spanwise but at average and particularly at high angles of attack large peaks of thinning form on the outer wing surfaces. Due to this factor the delta wing aircraft, contrary to the sweepback wing aircraft, does not tend to pitching or wing stall at low IAS, and its aileron effectiveness remains sufficiently good.

Directional stability of the delta wing aircraft is considerably higher than that of other type wing aircraft. This is displayed in Fig.17 which gives comparative characteristic

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of directional stability of aircraft with different wing forms.

The figure shows that with lift coefficient (C_L) increase, directional stability (C_n) of rectangular wing aircraft remains unchanged but that of the sweepback and delta wing aircraft increases. Directional stability of the delta wing aircraft, at that, improves better than that of the sweepback wing aircraft. Thus, for instance, if C_L coefficient rises from 0.2 to 0.8, directional stability of the sweepback wing aircraft will augment by 30 per cent and that of the delta wing aircraft - by 100 per cent.

Leading edge sweep angle of the MiG-21F-13 aircraft delta plan form wing is 57°, aspect ratio - 2.2, wing area - 23 sq.m. The wing consists of thin symmetrical profiles having thickness/chord ratio of 4.2 - 5 per cent. Thinner profiles are installed at the root of the wing. To decrease lateral stability the wing has negative wing dihedral equal to 2°.

Small aerodynamic fences are installed on the wing upper surfaces in front of the ailerons; the wing tips have small rakes which eliminate wing flutter at M-number 0.95 speed that appears as a result of insufficient rigidity of wing tip plates and variation of pressure shocks at wing tips. The port aileron is equipped with ground adjustable trim tab conceived for carrying out aircraft lateral balancing adjustment.

The wing is provided with flaps which improve carrying properties of the wing at take-off and landing. The flaps are of floating type. They can be extended at only one angle which will be decreasing with speed build up as a result of augmentation of aerodynamic load on the flaps. Extension of the flaps provokes insignificant pitching moment as a result of flaps increased downwash effect on the stabilizer.

Fuselage configuration has great importance for the supersonic aircraft, as fuselage drag share reaches 50 per cent of total aircraft drag. Nose section configuration is of [illegible] mount importance for the supersonic aircraft, particularly when

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the nose section houses engine air intake, as at supersonic speeds pressure shock originates in front of the fuselage.

Pressure shock is a very thin layer of air in which abrupt (shock type) braking of supersonic air flow occurs. In other words a gas impact, which can be compared to a water stream impact against hard obstacle, takes place in pressure shock. The difference consists in the fact that in case of water stream hitting hard obstacle, the stream speed is lost completely, while in pressure shock the air flow loses its speed only partially.

Sudden decrease of air flow speed on the surface of pressure shock and flow pressure increase are accompanied by air compression and augmentation of its density. At the same time temperature of the air rises. Thus, in pressure shock we observe irreversible transition of air flow kinetic energy into thermal energy, and this is one of the main reasons for occurence of additional drag (wave drag). Value of this drag depends on the amount of kinetic energy converted to thermal one, i.e., on loss of speed in pressure shock.

The greatest loss of speed and biggest rise of pressure occurs when the flow is passing through a normal shock (shock of pressure perpendicular to air flow speed).

The flow is slowed down in a normal shock to such an extent that behind a normal shock air flow speed drops below sonic. Therefore, occurence of a normal shock will entail the highest wave drag.

In an oblique shock the flow is slowed down less than in a normal shock and, consequently, wave drag will be lower. And if the shock angle of slope is close to the right angle, the flow speed behind the shock will also become subsonic, though somewhat higher than behind a normal shock. On decreasing oblique shock angle of slope, loss of speed in the shock, relatively to the onrush air flow speed, will be less significant and behind the oblique shock the speed becomes supersonic. At the same time pressure growth on the oblique shock decreases

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and this leads to attenuation of wave drag coefficient, correspondingly.

Type of a pressure shock depends on the configuration of the nose section of the body before which a shock originates, and also on the onrush air flow M-number.

When an obtuse body is streamlined by a supersonic flow, pressure shock of curvilinear form occurs in front of the body at certain distance from its nose section. Directly ahead of the body the shock will be a normal one as here it is perpendicular to the onrush air flow.

On retreating from the body shock angle of slope decreases and approaches conical sonic wave angle of slope. Consequently, in different points of such shock we witness different degrees of flow speed drop.

When a pointed body (for instance, wedge, cone or profile of a wing with sharp leading edge) is streamlined by supersonic flow, at first, a shock also occurs at a certain distance from the body nose section and at M-number slightly exceeding 1, is a normal one but of considerably lesser intensity and incurring lower losses than a normal shock ahead of an obtuse body does. With further increase of M-number the shock approaches the body nose and becomes an oblique one and beginning from a certain flow speed value the shock settles on the body nose point, i.e., the shock forward point is matched with the forward point of the body (Fig.18). A certain flow speed, beginning with which the shock settles on the body nose section point corresponds to a certain angle of taper. In this case a normal shock does not occur and losses incurred in the shock (wave drag) are lesser than in the case when an obtuse body is streamlined.

The form of pressure shock ahead of the fuselage nose section affects not only fuselage drag but engine thrust as well.

A normal shock, while slowing down the air flow, incurs higher losses of engine incoming flow pressure, that would

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have been in the case when air flow is slowed down smoothly, without shocks, and, consequently, fairly reduces engine thrust at high M-numbers of flight. In oblique shock or a succession of oblique shocks slow air flow down more smoothly, therefore, losses in engine incoming air pressure will be lesser and, consequently, degree of engine thrust reduction will be lower.

For the purpose of reducing fuselage external drag and supplying the engine with sufficient amount of air without incurring high losses in pressure and for the purpose of attaining uniform field of speeds and pressures of engine inlet air flow the aircraft is provided with a supersonic air intake. The diagram of a supersonic air intake with external compression, i.e., when the flow is slowed down from supersonic to subsonic speed in pressure shocks located ahead of and in the plane of duct entrance, is given on the right section of Fig.19. The left section of the figure displays a subsonic air intake, for the sake of comparison.

The figure shows that when the edges of a subsonic air intake have considerable radius of curve, those of a supersonic air intake are pointed; the latter factor leads to considerable reduction of the MiG-21 -1 aircraft fuselage external drag.

Forms and positions of pressure shocks displayed in Fig.19 correspond to Mach number exceeding 1. And at the supersonic air intake they correspond to the design M-number. In case of a subsonic air intake a normal pressure shock ahead of the fuselage within M-number range of 1 - 1.5 incurs comparatively low losses in engine inlet air pressure. Therefore, if maximum M-number of the aircraft in flight does not exceed 1.5, the air intake will not require special arrangement for reducing losses in engine inlet air pressure. But with further increase of M-number of flight these losses augment rapidly and at M = 2 they reach 28 per cent that leads to reduction of engine thrust by 34 - 48 per cent. For the purpose of decreas-

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ing these losses, the supersonic air intake with external compression is provided with an adjustable cone of special profile installed in the centre of the intake. When flying at supersonic speed, the cone provokes formation of one or several oblique shocks and of a tailing weak normal shock which is almost in the plane of the duct inlet as is shown in Fig.19b. Behind this tailing shock flow speed will be subsonic.

The figure shows three-shock system of flow slowdown consisting of two oblique and one normal shocks which slows the air flow down sufficiently smoothly, therefore, losses in air pressure are insignificant and at M = 2 they amount to about 3 per cent. To ensure reliable operation of the air intake, the duct is designed to have its walls first converging to the throat and then diverging (Fig.19b). Therefore, after a normal shock occurring at the beginning of the converging part of the duct, the air flow is accelerated from subsonic speed ($M < 1$) to sonic speed in the air intake throat ($M = 1$) and aft of the throat in the diverging part of the duct the flow attains supersonic speed ($M > 1$).

While moving further along the duct the supersonic flow encounters back pressure that leads to formation of a normal shock behind which the flow becomes subsonic ($M < 1$). The supersonic area created behind the throat detains some of the disturbances coming from engine side; this factor ensures stable operation of the air intake.

The right section of Fig.19 shows the most advantageous positions of oblique shocks, i.e., when they touch fuselage shell front edge, that usually occurs when the aircraft is flying at design M-number which in the case of the MiG-21F-13 aircraft is equal to 2. When flying at other M-numbers these positions of pressure shocks with the cone position unchanged are not to be expected. For instance, when flying speed is increased, the oblique shocks will go inside the air intake and when speed drops, the shocks will occur ahead of the fuselage shell front edge, as indicated in Fig.20.

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In the first case additional pressure shocks occur at the fuselage shell front edge, which leads to augmentation of fuselage drag and of losses in engine inlet air pressure. In the second case, the flow is partially diverted by the shock, therefore, not the whole air stream approaching the inlet (as is shown in the figure by dot line) but only its part indicated in the figure by dash-and-dot line enters the air intake. The result is that the amount of air entering the intake decreases and it may not be sufficient for ensuring normal operation of the engine.

The most advantageous location of pressure shocks is achieved by introduction of all-rating cone which automatically and smoothly changes its positions according to flying speed variations.

When the cone is extending, the intake throat area diminishes to the extent that provides for the amount of air required by the engine and at the same time prevents occurrence of intake unstable operation, i.e., occurrence of air intake surge.

Air intake surge occurs at high flight M-numbers in those cases when the amount of air passing through the duct exceeds the amount of air the engine is able to consume. Therefore, all those factors which contribute to the increase of air amount passing through the duct, as for instance, cone extension delay and others, or which reduce the amount of air consumed by the engine (r.p.m. drop), provoke air intake surge. In case of surge, air back-pressure ahead of the engine increases and, consequently, the normal shock in the duct behind the intake throat shifts forward. This leads, firstly, to shrinkage and then to disappearance of the supersonic area behind the throat and, consequently, to setting of subsonic speed in it. Then, under influence of high pressure, the falling normal shock, located at the duct inlet, passes behind the fuselage shell front edge and then enters the duct, and this phenomenon is repeated. These variations of pressure

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shocks bring about abrupt changes of speed and air pressure in the intake which leads to vibration and flops. The frequency of these variations is not high (about 4 - 6 c.p.s.). This is how air intake surge occurs.

Air intake surge at high flight M-numbers can be provoked also by disturbance of air flow in the duct, as happens in the case when the air flow enters the inlet at high angle of attack or slide.

Possibility of surge called for installation in the duct of front shutters which automatically open outside and, by-passing some of the air from the duct into atmosphere, reduce the pressure and, therefore, eliminate air intake surge.

When the aircraft is flying at M = 1.9 - 1.95, i.e., when the cone has reached its extreme forward position, air intake vibration occurs. At these M-numbers flow separation is experienced in the boundary layer from under the normal shock at the end of the supersonic area behind the intake throat. This phenomenon changes pressure behind the shock which entails oscillatory movements of the shock at 40 - 50 c.p.s. frequency. In case of low structural rigidity of this section of the duct high-frequency vibration will develop in the duct and will be accompanied by sound effect of high tone. Air intake high-frequency vibration somewhat reduces engine thrust but the flying will be safe.

The duct is provided also with rear shutters, designed for increasing thrust at take-off by supplying additional amount of air to the engine. The shutters are not positively controlled and operate on the effect of pressure differential inside and outside the duct. The shutters open inside when the engine is running on the ground and also at take-off and in flight in case of rarefaction in the duct. Augmentation of speed and, consequently, of velocity head increases pressure in the duct and leads to shutters closure.

When the aircraft is in spin, one of the shutters will be open to ensure normal operation of the engine. The shutter

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opens due to aircraft side slipping in spin and due to pressure differential outside and inside the duct experienced during this process. With the shutters closed the engine may cut-off on the first turn of the spin.

There are three air brakes, total area about 1.3 sq.m., installed on the fuselage underside near the wings. Two forward air brakes deflect by 25° and the rear one - by 40°. When the air brakes are extended, aircraft drag coefficient maximum growth will be attained at M = 1.2 and will be equal to 0.03. Extension of the air brakes provokes slight pitching moment.

The MiG-21S-13 aircraft has a conventional empennage configuration used for modern supersonic aircraft.

Vertical tail surface consists of an uncontrollable vertical fin and a rudder which is controlled without hydraulic amplifier. It is made of symmetrical profiles having thickness chord ratio of 6 per cent. The rudder is provided with a gear adjustable tab enabling the pilot to effect directional balancing of the aircraft, and with an anti-flutter load. The fuselage tail section is equipped with a ventral fin blade to improve directional stability of the aircraft.

The horizontal empennage consists of a controllable stabilizer operated via a two-chamber hydraulic amplifier.

The stabilizer is composed of symmetrical profiles having thickness/chord ratio of 6 per cent. It is provided with a bent-up tab to decrease stabilizer hinge moment. Anti-flutter loads are fitted on the stabilizer tips in front of the leading edge. Maximum deflection angles of the stabilizer are: nose section up +13°, nose section down -28°.

Aircraft Flight Characteristics

The basic flight characteristics of the fighter aircraft ascertaining its abilities in air combat are level flight maximum speed, rate of climb, ceiling, maneuverability in horizontal and vertical planes as well as range and endurance.

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Most of the indicated characteristics depend on value and character of change of net and required thrusts for a given aircraft. The thrust with afterburning of modern turbojet engines depends largely on engine limitations and on specific features of engine fuel supply automatic control system. When the MiG-21F-13 aircraft is flying in the stratosphere, the net thrust with afterburning will grow with the increase of M-number up to 1.8 - 1.9, though further increase of M-number above the indicated value will lead to reduction in the thrust. This procedure of net thrust change is explained mainly by the fact that with augmentation of flying speed air gravimetric per second consumption of the engine grows and this leads to increase in engine thrust. But at M-number of the order of 1.8 - 1.9 the amount of fuel delivered to the engine becomes limited and the engine thrust changes insignificantly with further increase of M-number. Besides, losses in the aircraft duct augment and, consequently, engine required thrust decreases. With flying altitude increase the required thrust is dropping as a result of the reduction in air gravimetric consumption by the engine.

When flying at low altitudes, increase of speed within transonic speed range leads to abrupt rise of the required thrust (aircraft drag) though at high supersonic speeds growth of the required thrust is delayed. This character of change of the required thrust is explained by the fact that at transonic speeds aircraft drag coefficient is augmenting intensively, while at supersonic speeds it decreases smoothly.

With altitude increase required thrust growth is slowed down considerably when flying speed builds up. Thus, for example, at H = 5000 m. the required thrust at M-numbers within 0.5 - 1.5 range augments almost ten times, but at altitudes close to aircraft ceiling and at M-numbers 1.2 - 2.2 it increases by 10 per cent only. This delay in aircraft drag growth is due to the fact, that at high altitudes the aircraft is flying at high angles of attack, when wing induced drag

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has considerable share in aircraft drag; as augmentation of speed is accompanied by decrease of angles of attack, therefore, at high altitudes it will lead to intensive reduction of induced drag, and this accounts for slow growth of aircraft drag.

At M-numbers equal to 1.5 and 1.9 aircraft drag changes suddenly due to cone position variations. Cone extension leads to drag reduction while its retraction provokes drag rise.

The basic flight characteristics of the MiG-21 -15 aircraft and their change due to the character of net and required thrusts variation when altitude and M-number change are discussed in the following paragraphs.

Level Flight Maximum Speeds

The MiG-21 -15 aircraft level flight maximum speed, when afterburning is used, will be supersonic at all altitudes of flying. At altitudes below 12,500 m. aircraft thrust-to-weight ratio allows to attain speed exceeding maximum permissible IAS (V_{IAS} = 1200 km/hr), and maximum permissible M-number (M = 2.1) at altitudes above 12,500 m. and close to the aircraft ceiling. Pilots must bear it in mind while flying the aircraft.

Fig.21 gives values of level flight maximum speeds of the MiG-21F-15 aircraft without external suspensions as they vary according to flight altitude and engine operation rating changes as well as values of level flight maximum speed variation when the aircraft is provided with a drop tank and is flying at altitudes close to its ceiling with afterburner on.

The figure indicates that level flight maximum speed at full thrust with afterburning attains its maximum value, about 2.500 km/hr, at H = 14,000 m.

When flying altitude decreases below 14,000 m., level flight maximum speed drops due to intensive growth of aircraft drag and due to engine net thrust limitations because of engine structural strength factor.

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When flying altitude is increased above 14,000 m., level flight maximum speed will reduce mainly due to increase of angle of attack and, consequently, of aircraft drag coefficient and at altitude ceiling of the aircraft (19,800 m.), it will have one value (V_{TAS} = 1912 km/hr) corresponding to M-number (1.8) of flight.

As is shown in Fig.24, when the aircraft is provided with a drop tank and is flying at full thrust with afterburning power setting, level flight maximum speed at altitudes close to the aircraft ceiling will considerably exceed maximum permissible M-number M = 1.6 (V_{TAS} = 1700 km/hr).

At full thrust without afterburning level flight maximum speed (1210 km/hr) will be at the ground level. With flying altitude increase it is dropping slower than speed of sound and, therefore, at altitudes from 1500 m. to 12,500 m. it becomes supersonic. At 14,500 m. cruising level flight speed V_{TAS} at this power setting will have one value and will correspond to 950 km/hr.

Speed and G-Load Limitations

The aircraft has the following limitations determined by structural load and stability limitations of the MiG-21-13 aircraft.

With Special Missiles K-13

Maximum permissible IAS ..... 1200 km/hr
Critical M-number of flight 2
Maximum permissible operational G-load 7

With special missiles K-13 and drop tank

Maximum permissible IAS ..... 1000 km/hr
Critical M-number of flight 1.6
Maximum permissible operational G-load 6

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Climbing

The MiG-21 -13 aircraft rate of climb varies within fairly wide range depending on engine power setting, presence of external suspensions (special missiles and drop tank) and climbing conditions.

Fig.22 shows barograms of three versions of climbing to static ceiling by an aircraft carrying no external suspensions and by an aircraft carrying external suspensions without using afterburning.

The first version of climbing is an optimum one as to the time factor. Take-off and climbing to static ceiling at supersonic speed are accomplished at full thrust with afterburning; take-off with flaps down; aircraft acceleration at ground level to TAS 1050 km/hr and climbing at this speed to 5000 m.; climbing from 5000 m. to 12,000 m. and at the same time accelerating the aircraft to TAS 1910 km/hr (M-number = 1.8). Climbing to ceiling - at M = 1.8. Time to reach ceiling - 7.5 min. Fuel consumption - 1140 kg.

The second version of climbing is an optimum one as to the fuel consumption factor. Take-off and climbing to 10,000 are accomplished at full thrust power setting and further climbing above 10,000 m. - at full thrust with afterburning power setting; take-off with flaps down; acceleration of the aircraft at ground level to TAS 950 km/hr and climbing at this speed to 10,000 m.; climbing from 10,000 to 12,000 m. at full thrust with afterburning and accelerating the aircraft to M-number 1.8; climbing to static ceiling - at supersonic speed of M = 1.8. Time to reach ceiling - 11 min. Fuel consumption - 1000 kg.

The third version, as compared with the second one, offers gains in time - 2 min., and in fuel consumption - 120 kg and consists in usage of kinetic energy of aircraft motion in climbing though some speed will be lost. The procedure of take-off and climbing to 8000 m. is the same as in the second

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version. Beginning from 8000 m. afterburning power will be set and the aircraft will climb to 12,000 m. with acceleration to M = 1.9. After that, the aircraft assumes climbing attitude with angle of climb higher, than in the second version, so as to climb to the ceiling at supersonic speed with gradual decrease in M-number and to attain M-number 1.6 at the ceiling. Time to reach ceiling - 9 min. Fuel consumption - 880 kg.

Climbing to 10,000 m. at full thrust is performed:

(a) with two rocket pods УБ-16-57 for unguided rocket missiles - at TAS 900 km/hr, time to climb - 5.5 min.;

(b) with two rocket pods УБ-16-57 for unguided rocket missiles and a drop tank - at TAS 830 km/hr, time to climb - 7.5 min.

When the aircraft is equipped with a drop tank and the engine is running at full thrust, power setting service ceiling (H_{ser} = 13,450 m.) is reached during 16.3 min.

When climbing to static ceiling at supersonic speed the МиГ-21 -15 aircraft has two characteristic conditions of climbing: subsonic one (V_{TAS} = 950 - 1050 km/hr) for climbing mainly in troposphere and supersonic one (M = 1.8) for climbing in stratosphere. Transition from subsonic condition of climbing to supersonic one is accomplished by accelerating the aircraft in climbing attitude from TAS 950 - 1050 km/hr to M = 1.8 at altitudes from 8000 - 10,000 to 12,000 m. depending on the version of climbing chosen by the pilot.

Vertical velocity maximum values in subsonic condition of climbing with different load variations and at all power settings are attained at ground level. After the aircraft is accelerated to M = 1.8 in climbing to 12,000 m., maximum vertical velocity of steady climbing at this M-number will be attained at, approximately, 12,000 m. With further increase of altitude it will experience continuous drop.

Vertical velocity dependence upon surplus thrust value, gross weight and climbing speed is seen from the equation:

$$V_{vert} = \frac{\Delta P}{G} \cdot V_{climb}$$

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where: ΔP is surplus thrust, i.e., difference between engine thrust and required one at a given flying speed;

V_{climb} is climbing speed;

G is gross weight of the aircraft.

Vertical velocity drop with altitude in subsonic and supersonic conditions of climbing is caused by surplus thrust value decrease. The latter, in its turn, diminishes due to the fact that engine thrust decreases with altitude more intensively than required thrust. At high altitudes (above 11,000 m.) surplus thrust drop becomes more intensive and it accounts for sharp reduction of vertical velocity.

It was indicated above that climbing would be accomplished within minimum time interval at full thrust with afterburner on when the first version of climbing is used. In this case the aircraft is climbing at maximum rate of climb.

Fig.23 displays rate of climb and M-number relation curves when the aircraft is climbing in troposphere and stratosphere. The figure indicates that in troposphere it is advisable to climb in definite subsonic condition, i.e., at a speed of 1450 km/hr at which maximum rate of climb is attained, and in stratosphere the aircraft should be flown also at definite but in this case supersonic power setting, i.e., at M = 1.8 at which the aircraft has maximum rate of climb in stratosphere; this procedure will ensure climbing in the least time.

When the aircraft is climbing without external suspension and the engine is running at full thrust with afterburner on the vertical velocity will be, m/sec.:

at 1000 m. 142.5
at 5000 m. 117.5
at 16,000 m. 87
at 19,000 m. 18.5

Vertical velocity values, m/sec. at full thrust power setting are given in Table 3.

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Table 3

H, m.	Without external suspensions	With drop tank	With two APC-57 missiles	With two APC-57 missiles and drop tank
1000	77.5	68.5	57	42
10,000	21	15.5	11	7.5

Time of climbing varies in accordance with vertical velocity character of change, as

$$t_{climb} = \frac{H}{V_{average\ vert}}$$

where: t_{climb} is time for climbing;

H - altitude;

V - average vertical velocity at a given section of climb.

As the average vertical velocity in steady climbing reduces with altitude increase, the time required for climbing to a specific altitude at a given climbing power setting will increase correspondingly.

The service ceiling of the aircraft flying at full thrust with afterburning power setting will be:

(a) without external suspensions - 19,800 m.

(b) with drop tank - 17,500 - 18,000 m.

The ceiling of the aircraft flying at full thrust power setting will be equal to:

(a) without external suspensions - 14,500 m.;

(b) with drop tank - 13,450 m.;

(c) with drop tank and two APC-57 missiles - 11,700 m.

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When the MiG-21 -13 aircraft, equipped with two missiles and a drop tank, is in climbing, it is recommended to maintain the following flight condition:

(a) to take-off and climb to 8[illegible] m. at full thrust; to maintain 930 km/hr during climbing;

(b) to set full afterburning power at 8[illegible]0 m. and to climb to 13,000 m. after accelerating the aircraft in level flight to M = 1.6 (when the aircraft is equipped with missiles and a drop tank) and to M = 1.85 (when only missiles are carried);

(c) further climbing to be accomplished at constant M-number (M = 1.6 or 1.85). The service ceiling 18,[illegible] - 19,000 m. is reached when the aircraft is flying without a drop tank.

Amount of fuel left when the ceiling is reached - 350 kg. When the aircraft is flying with two missiles and a drop tank service ceiling will be limited to 17,500 m. Amount of fuel left when this ceiling is attained - 900 kg.

Table 4 presents fuel consumption, time and distance covered during take-off and climbing at full thrust power setting for the MiG-21 -13 aircraft equipped with R-11 -3 engine.

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Table 4

Altitude, m.	Without external suspensions (with pylons and beams), TAS in climb - 930 km/hr			With two special missiles K-13, TAS in climb - 930 km/hr			With two special missiles K-13 and drop tank, TAS in climb - 930 km/hr		
	fuel consumption, kg	time, min.	distance, km.	fuel consumption, kg	time, min.	distance, km.	fuel consumption, kg	time, min.	distance, km.
1000	70	1.3	5	80	1.5	5	100	2	10
5000	160	3	30	185	3.3	35	210	4.2	45
8000	215	4	50	250	4.9	60	290	6.4	75
10,000	250	5.2	65	310	7.1	90	360	8.2	110
11,000	270	6	85	340	8.4	110	400	9.8	130

Fuel consumption, time and distance for gliding are given in Table 5.

Table 5

Altitude, m.	Fuel consumption, kg	Time, min.	Distance, km.
5000	20	3	35
8000	40	5	60
10,000	60	7	85
11,000	75	8	100
17,500	120	13	165
20,000	135	14	180

Notes: 1. Gliding is performed at idle speed.
2. Air brakes are retracted.

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Aircraft Maneuverability

Aircraft maneuverability is defined as its ability to change its position in space during a certain period of time. It is characterized by swiftness of change of value and direction of flying speed. There are two kinds of maneuverability: horizontal and vertical.

Maneuverability properties of the aircraft depend mainly upon speed of its motion along a trajectory and upon G-loads acting in direction of vector of speed (n_x) and perpendicularly to vector of speed in the plane of aircraft symmetry (n_y). These G-loads, as also all other flight characteristics of aircraft, depend largely on the conditions under which a given maneuver is executed. These conditions of flight comprise, above all, altitude and speed of flight, engine power setting and flight technique.

Dependence of Net G-Loads on Altitude and M-Number

Normal G-load (n_y) is a number indicating relation of aircraft lifting force at a given flying condition to aircraft weight, i.e.,

$$n_y = \frac{Y}{G}$$

Dependence of net G-loads (n_y) of the MiG-21F-13 aircraft upon altitude and M-number is shown in Fig.24.

Up to M = 1.1 aircraft net G-loads are limited by maximum value of lift coefficient (C_L), and at M-numbers exceeding 1.1 they are limited by maximum possible deflection of the stabilizer.

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As is shown in the Figure, at constant altitude G-loads augment with increase of M-number up to 1.1, but at further increase of M-number from 1.1 to 1.5 the G-loads reduce due to intensive drop of $C_{L_{max.}}$ coefficient at these M-numbers. When M-number is augmented above 1.5, aircraft net G-loads begin to grow again. If altitude is increased but M-number remains constant, net G-loads reduce. When the aircraft is operating at its static ceiling and at M = 1.8, net G-loads will be, approximately, 1.5.

The MiG-21F-13 aircraft aerodynamic arrangement is conceived to withstand the above discussed G-loads, but the aircraft can be subjected to them only for short periods of time in an unsteady flight with loss of speed. Prolonged G-loads in steady flight, for instance in turn, which are provided for by the engine thrust, are usually smaller than net G-loads of short duration.

Aircraft Horizontal Maneuverability

Maneuverability properties in horizontal plane are estimated through characteristics of aircraft acceleration and slowing down in rectilinear motion and through characteristics of maximum turns (i.e., steady, with maximum G-loads) in curvilinear motion.

Characteristics of aircraft acceleration and slowing down will be discussed first.

The aircraft ability to change its speed value is characterized by the time of acceleration and slowing down in rectilinear level flight.

Acceleration in level flight is accomplished by increasing engine r.p.m. and by setting afterburning power. The surplus thrust, thus obtained, accelerates the aircraft along the trajectory of flight.

Speed in level flight is reduced by cutting off afterburning power, by decreasing engine r.p.m. to the

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M-number below 1.5, and by slowing down the aircraft by using air brakes.

Acceleration ability of the aircraft depends on the thrust-to-weight ratio and on aerodynamic properties, while braking ability depends only upon aerodynamic property.

As compared with its predecessors the MiG-21-13 aircraft has higher thrust-to-weight ratio and, therefore, it accelerates quicker. Specific feature of aircraft acceleration at supersonic speed and at altitudes above 10,000 m. is the fact that acceleration grows when the speed is augmented to, approximately, M = 1.8 which is explained by surplus thrust increase at this M-number.

Time for the MiG-21-13 aircraft acceleration is shown in Fig.25.

The graph shows that it takes 3 min. to accelerate the aircraft in level flight from 1000 to 2100 km/hr at 13,000 m. With altitude increase acceleration time augments due to decrease of rate of acceleration as surplus thrust drops when altitude is augmented. Thus, at 15,000 m. it will take 5 min. 15 sec. to accelerate the aircraft from 1000 to 2100 km/hr, i.e., acceleration time augments by 1.75 times.

Fig.26 presents variations of time required for slowing down the MiG-21-13 aircraft with air brakes down and after burner cut off (engine is operating at full thrust down to M = 1.5) and further decrease of engine power to idle speed at M-numbers below 1.5.

The graph indicates that to slow down the aircraft in level flight from 2170 km/hr to 1200 km/hr it will take 50 sec. at 13,000 m. and 1 min. 7 sec. at 15,000 m. Therefore augmentation of flight altitude increases the time required for slowing the aircraft down at supersonic speeds, due to aircraft drag reduction.

A curvilinear maneuver in horizontal plane is usually evaluated by characteristics of the maximum turn.

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Fig.27 displays a graph of dependence of maximum radii and time of turns of the MiG-21F-13 aircraft without external suspensions flying at afterburning power setting upon flying speed at altitudes of 500 - 15,000 m.

The Figure indicates, that in troposphere the least time of turn corresponds to TAS = 1000 km/hr and at 5000 m. will be 36 sec. (load factor n_y = 5.5). In stratosphere at altitudes close to stratosphere boundary, the least time of turn in supersonic flight will be obtained at TAS = 1350 km/hr, and with speed augmentation up to 1800 km/hr time of turn changes insignificantly, which is accounted for by maximum G-load growth in turn up to M = 1.8. Speed increase above 1800 km/hr leads to intensive growth of time of turn.

At altitudes close to the aircraft ceiling the least time of turn corresponds to M-number equal to 1.8 at which G-loads in turn are maximum in stratosphere.

The smallest radius of curve in troposphere corresponds to TAS = 800 km/hr and at 5000 m. will be 1500 m. In stratosphere at altitudes, neighbouring its boundary, the smallest radius of curve in supersonic flight corresponds to minimum flying speeds and with augmentation of speed the radius of curve increases. At altitudes close to the aircraft ceiling the smallest radius of curve will be at M = 1.8 (V_{TAS} = = 1912 km/hr).

As is indicated in the graph augmentation of altitude at constant speed leads to increase in radius and duration of turn, caused by decrease of maximum G-load in turn.

With the stabilizer fully deflected the aircraft behaves normally in turn at supersonic speeds but shaking vibration occurs during transition from supersonic speed to subsonic one. Execution of unsteady turn at M-numbers within 1.9 - 1.4 range, with the stabilizer fully deflected, leads to reduction of radius and duration of turn at 12,000 m., the latter will be twice as small as those of maximum turn. At lower and higher M-numbers radius and duration of unsteady turn at maximum speed reduce in greater degree.

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Aircraft Vertical Maneuverability

Maneuverability properties in vertical plane are evaluated by characteristics of upward acceleration, for instance, chandelle and zoom and by characteristics of downward acceleration for example, half-roll and dive.

The MiG-21 -15 aircraft possesses high maneuverability performance in vertical plane due to great range of aircraft speeds, sufficiently great thrust-to-weight ratio and sufficiently high accelerating load limits.

Specific feature of chandelle and zoom is a considerable altitude gain during execution of these maneuvers, possible only while using great kinetic energy of the aircraft flying at afterburning power setting. Thus, for example, while executing chandelle and zoom, if the maneuvers are entered at IAS = =1000 km/hr, at full thrust power setting the aircraft climbs from 5000 m. to 9500 - 10,000 m.; if they are entered at the same speed but at full thrust with afterburning power setting the aircraft can climb from 5000 to 14,000 m. and the altitude gained will be considerably higher if the maneuvers are entered at maximum permissible speed. When a half-roll is executed and the maneuver is entered at altitudes between 6000 - 10,000 m. and at IAS = 400 - 600 km/hr the loss of altitude will be 3000 - 5000 m.

With altitude increase in stratosphere the MiG-21 -15 aircraft vertical maneuverability deteriorates mainly due to reduction of accelerating load limits, thrust-to-weight ratio and range of flying speeds.

Range and Endurance

To obtain maximum range and endurance in level flight it is necessary to maintain IAS indicated in Table 6.

Augmentation of altitude increases range and endurance; maximum range and endurance can be obtained at 11,000 - 12,000 m.

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Range and endurance estimates take into account the following:

Fuel consumption during engine ground operation (starting and engine test run, taxiing to the runway and taxiing from the runway) for 7 min. ..... 60 kg

Fuel consumption, time and distance at take-off and climbing and at gliding .... as indicated in tables below

Fuel consumption on circuit flight before landing, for 4 min. ..... 80 kg

Trapped fuel ..... 30 kg

7 per cent fuel reserve ..... 120 kg

at γ = 0.775 gr/cu.cm.

and 125 kg

at γ = 0.83 gr/cu.cm.

Table 6 presents service range and endurance (with subtraction of 7 per cent allowance for fuel reserve) of the MiG-21F-13 aircraft, equipped with the R-11F-300 engine, flying at 11,000 m. without external suspensions (with pylons and beams) or with two K-13 missiles, or with two K-13 missiles and a drop tank.

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Table 6

Service range and endurance (with 7 per cent allowance for fuel reserve) of MiG-21Ф-13 aircraft, equipped with P-11Ф-300 engine, at 11,000 m.

Flight condition	Flying speed, km/hr		Engine low-pressure rotor r.p.m., per cent	Fuel per km. consumption, kg/km.	Fuel per hr consumption, kg/hr	Range, km.		Endurance, hr-min.	
	IAS	TAS				level flight	service	level flight	service
1	2	3	4	5	6	7	8	9	10
Without external suspensions (with pylons and beams)									
Initial gross weight ..... 6965 kg									
Total fuel ..... 1965 kg (2300 lit.)									
Fuel available for cruising ..... 1260 kg									
Maximum range	520	925	87	0.9[illegible]	[illegible]	129	147[illegible]	1 - 04	1 - 4[illegible]
Maximum endurance	440	795	85	1.0[illegible]	[illegible]	[illegible]	13[illegible]	1 - 0[illegible]	1 - [illegible]

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With two K-13 missiles

Initial gross weight ..... 7110 kg
Total fuel ..... 1905 kg
Fuel available for cruising ..... 1190 kg

Maximum range	520	925	91	1.09	1010	1090	1300	1 - 11	1 - 31
Maximum endurance	440	795	89	1.17	930	1020	1230	1 - 17	1 - 37

With two K-13 missiles and 490-lit. capacity drop tank jettisoned after its fuel is used

Initial gross weight ..... 7560 kg
Total fuel ..... 2315 kg
Fuel available for cruising ..... 1540 kg

Maximum range	520	925	92	1.14	1060	1350	1580	1 - 27	1 - 49
Maximum endurance	440	795	90	1.23	930	1250	1480	1 - 34	1 - 56

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In calculations of aircraft range and endurance allowances are made for the following:

Fuel consumption during engine ground operation (starting, ground test and taxiing) for 7 min. ..... 60 kg

Fuel consumption, distance and time for take-off and climbing and for gliding .. in accordance with Tables 4 and 5 data.

Fuel consumption for circuit flying prior to landing, during 4 min. ..... 80 kg

Trapped fuel ..... 30 kg

7 per cent fuel reserve ..... 130 kg

Fuel specific weight ..... 0.83 gr/cm³

The estimates take into account the fact that K-13 missiles are not dropped in flight.

Take-off and Landing Characteristics

Take-off run of the MiG-21-13 aircraft carrying K-13 missiles and operating at full thrust power setting with flaps down is about 1200 - 1250 m., unstick speed being 325 km/hr.

The MiG-21-13 aircraft take-off run at full thrust with afterburning with flaps down will be:

when carrying K-13 missiles ..... 700 - 830 m.

when carrying K-13 missiles and drop tank ..... 880 - 1020 m.

Unstick speed will be:

when carrying K-13 missiles ..... 325 - 330 km/hr

when carrying K-13 missiles and drop tank ..... 330 - 350 km/hr

Aircraft landing run when landing with flaps down will be:

brakes applied to three wheels ..... 1200 - 1300 m.

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brakes applied to three wheels
and brake chute ejected ..... 900 - 1050 m.

Take-off run depends not only on aircraft load version and engine power setting but on ambient temperature and aircraft unstick speed as well.

Increase in aircraft loading, unstick speed, ambient temperature and reduction of engine power setting will augment aircraft take-off run.

According to rough estimates, when the weight of aircraft, using concrete runway for take-off, does not change much, it may be said that augmentation of aircraft weight by 1 per cent increases take-off run by 2 per cent and ambient temperature rise by 1 degree increases take-off run by 1 per cent.

Aircraft landing run depends upon landing speed, aircraft weight, ambient temperature and pressure, and effectiveness of aircraft braking. By roughly estimating the influence of slight variation of the above indicated factors on landing run, it may be considered that:

(a) aircraft position at touchdown being normal, aircraft weight change by 1 per cent changes landing run by 1 per cent too;

(b) touchdown speed change by 1 per cent changes landing run by 2 per cent;

(c) outside air pressure change by 1 per cent changes landing run by 1 per cent;

(d) ambient temperature change by 3 degrees changes landing run by 1 per cent.

Stability and Controllability Characteristics

Aircraft stability is stipulated by location of its centre of gravity and aerodynamic centre. Stability of the MiG-21-13 aircraft carrying no external swep[illegible] at all ranges of speeds and altitudes and provides [illegible] behaviour of the aircraft.

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Aircraft controllability is stipulated largely by such features of the aircraft control system which in case of the MiG-21 -13 aircraft consist mainly in the fact that the stabilizer and aileron controls are conceived to use power drives of the hydraulic amplifiers connected in irreversible circuit and that the rudder is controlled without hydraulic amplifiers. Spring loading mechanism, creating loads on the stick according to a certain law, are introduced into stabilizer and aileron control systems so as to enable the pilot to feel the controls. Besides, the directional control system incorporates a "trimming effect" mechanism and the [illegible] automatic transmission ratio control unit, which depending on speed and altitude variations, automatically changes control stick-to-stabilizer transmission ratio and control stick-to-spring loading mechanism transmission ratio, while the lateral control system is provided with transmission ratio non-linear change mechanisms, installed before the boosters, facilitates control when the ailerons deflect from neutral position also third of their total angle of deflection (this is necessary when the boosters are inoperative) and ensuring satisfactory sensitiveness of aircraft lateral control at high speeds.

The aircraft has an ability to rapidly change the angle of attack at the first moment and retard changing of speed, in case when balance is disturbed. Due to this factor the aircraft longitudinal stability has two meanings:

(a) stability at the first moment of motion after balance of the aircraft is disturbed when the angle of attack changes but the speed remains actually constant;

(b) stability at the consequent moments of motion of the aircraft when mainly the speed is changing while the angle of attack remains almost unchanged.

The first type of stability is called G-load stability, the second one - speed stability.

In the aircraft controllability evaluation the priority is given to G-load stability.

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G-load stability. The aircraft is deemed stable as to G-load variations if it tends to maintain a given flight condition G-load without pilot's interference.

In steady straight flight at constant speed all forces and moments acting on the aircraft are balanced. It can be derived from the G-load stability definition that during G-load and, consequently, angle of attack variations, the moments acting on the aircraft must change so, that a turn of the aircraft, induced by these moments, would return the aircraft to its original G-load.

Let us assume that the aircraft hits an upward air stream and as a result of this angle of attack increases by value $\Delta\alpha$ (Fig.28), and, consequently, lifting force augments by value Δv If the aircraft experiences lifting force growth in a point located behind the aircraft centre of gravity, diving moment ΔM occurs which will decrease angle of attack and, consequently, G-load factor. Such aircraft is considered to be stable as to G-loads.

If the aircraft experiences lifting force growth at a point located ahead of the aircraft centre of gravity, pitching moment occurs which provokes further augmentation of angle of attack. Such aircraft will be unstable as to G-loads. The point which experiences the growth of lifting force only during variations of angle of attack in flight at constant speed is called the aircraft aerodynamic centre.

Thus the G-load stability of the aircraft is determined by space relationship of centre of gravity and aerodynamic centre of the aircraft.

Fig.28 displays stable and unstable aircraft as to G-load.

The aircraft is stable as to G-load if its centre of gravity is located ahead of its aerodynamic centre, and the longer is the distance between the centre of gravity and the aerodynamic centre, the more stable is the aircraft as to G-load; diminution of the distance between the centre of

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gravity and the aerodynamic centre leads to deterioration of stability.

Balancing of the aircraft is called neutral when location of aircraft centre of gravity coincides with that of aerodynamic centre. In this case the aircraft will not respond to balance disturbances.

When the centre of gravity is further offsetting rearward, the aircraft becomes unstable as to G-load. G-load stability in flight may change due to aircraft centre of gravity location change or due to offsetting of the aerodynamic centre. In the MiG-21F-13 aircraft the centre of gravity moves within 31.5 - 36 per cent MAC limits due to fuel consumption, landing gear position, availability of armamentin, availability of a drop tank and missiles.

In the MiG-21F-13 aircraft the aerodynamic centre moves aft under the effect of air compressibility when M-number of flight is increased above 0.9. In case of the delta wing aircraft, when M-number of flight is increased above M_{crit}, the aerodynamic centre moves aft within a considerably smaller range then in sweepback wing aircraft, therefore, MiG-21F-13 aircraft G-load stability changes less at transonic and supersonic speeds.

The MiG-21F-13 aircraft is stable as to G-load within the entire range of altitudes and speeds. Ventral tank and missiles suspension leads to considerable deterioration of aircraft G-load stability. This deterioration is partly explained by the fact that the larger part of the tank and missiles is ahead of the aircraft centre of gravity and as a result of this their lifting forces passing in front of the aircraft centre of gravity provoke a pitching moment which leads to deterioration of G-load stability.

G-load stability and curvilinear motion controllability are closely related. G-load stability of the aircraft determines the most important characteristic of its controllability G-load effort gradient, i.e., the effort to be additionally applied to the stick to increase load per unit.

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Availability of hydraulic amplifier, operating on irreversible circuit, spring loaded mechanism and the AVJ-5B automatic unit in the stabilizer control system influences the load effort gradient considerably. In case of the MiG-21F-13 aircraft the load effort gradient depends mainly upon flying speed and altitude and is related to effectiveness of the stabilizer.

Stabilizer effectiveness is determined by the value of its lifting force. Therefore, speed increase requires smaller deflection of the stabilizer, while augmentation of altitude demands greater deflection of the stabilizer in order that the stabilizer lifting force provides for a sufficient moment to overcome the moment originated by the wing lifting force. When the control stick is deflected, the spring loaded mechanism, incorporated in the system of longitudinal control, provides for load on the stick directly proportional to stabilizer deflection angle. Therefore, at augmentation of M-number to 0.8 - 0.9 when stabilizer efficiency grows, required angle of stabilizer deflection and, consequently, load effort gradient will decrease as indicated in Fig.29 which displays graphs of variation of load effort gradient ($\frac{dp}{dn}$) of the MiG-21F-13 aircraft carrying no external suspensions, according to M-number and altitude of flight.

In case of M-number increase from 0.8 - 0.9 to 1.5 when wing aerodynamic centre moves aft, wing lifting force moment increases and greater deflection of the stabilizer will be necessitated to augment G-load per unit. This leads to load effort gradient growth. For instance, Fig.29 shows, that in case M-number is increased from 0.8 to 1.5 at 15,000 m., load effort gradient will grow almost twice.

After the wing aerodynamic centre has reached its extreme aft position, further increase in M-number above 1.5 will be accompanied by reduction of load effort gradient. In case of altitude increase when greater deflection of the stabilizer

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is required to augment G-load per unit, load effort gradient increases.

As is shown in Fig.29, altitude increase from 1[illegible],000 to 20,000 m. at M = 1.5 augments load effort gradient by more then four times.

With altitude increase, oscillatory motions of the aircraft attenuate more slowly than at low altitudes. This phenomenon is particularly noticeable at afterturning power setting and at altitudes close to aircraft ceiling and is largely due to decrease of damping moments at aircraft oscillations as a result of air density drop when altitude is increased.

Aircraft speed stability. The aircraft is considered to be stable as to speed, if it maintains the speed of the trim flight condition without pilot's interference.

Speed stability of an aircraft means that augmentation of speed increases lifting force while reduction of speed leads to lifting force decrease. In this case, speed augmentation (for instance, when flight path deflects down arbitrarily) will be accompanied by positive growth of lifting force, which will make the aircraft to assume climbing attitude and return it to the previous speed (Fig.30).

If for one reason or another, the flying speed drops (for example, when the aircraft assumes climbing attitude though power setting is not changed), lifting force decrease will entail deflection of the flight path down and recovery of the previous speed. As the lifting force is proportional to speed square, it seems at first that the aircraft is always stable as to speed. This is not the case, however. If for instance, augmentation of speed is accompanied by occurrence of a great diving moment, which highly decreases the angle of attack, then regardless of speed growth lifting force decreases and aircraft speed stability deteriorates.

If the aircraft is stable as to speed, then, to change the latter the pilot must correspondingly deflect the control and, by changing the effort on the control stick, must overcome

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come aircraft tendency to maintain the initial speed. Due to this factor, with speed augmentation the aircraft, which is stable as to speed, will tend to assume climbing attitude. To counteract this tendency, the pilot must move the stick forward, when speed grows.

Thus, speed stability is interconnected with the control stick effort the pilot has to apply to keep the stabilizer in the position necessary for aircraft balancing.

Curves of dependence of stabilizer deflection angles necessary for aircraft balancing at various speeds in level flight are called the balancing curves.

Fig.31 displays the balancing curves of stabilizer deflection for the MiG-21 -13 aircraft. It shows that when M-number is increased to about 0.9, stabilizer deflection angle is to be decreased. This change of stabilizer balancing deflections testifies to speed stability of the aircraft. With further augmentation of M-number to about 1.2, stabilizer deflection angle is to be increased. This factor indicates the aircraft speed instability.

The MiG-21 -13 instability as to speed is very slightly manifested in the form of insignificant increase of diving efforts on the stick within M-numbers equal to 0.9 - 1.2.

Instability as to speed is caused by displacement of centre of pressure aft due to asymmetrical development of wave stagnation on the upper and lower surfaces of the wing and due to consequent occurrence of diving moments at these speeds.

When M-number is increased above 1.2, asymmetry in wave stagnation development diminishes and the aircraft becomes neutral, at first, and when the speed approaches M-number 1.6 - 1.7 it recovers its stability as to speed.

MiG-21 -13 aircraft speed instability is little felt by the pilot and does not complicate flying.

Longitudinal controllability of aircraft. Longitudinal controllability of the aircraft is largely provided for by

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the spring loaded mechanism, incorporated in the aircraft longitudinal control system, and by the stabilizer control stick and automatic transmission ratio control unit that increases the load on the stick when IAS grows from 450 to 1010 km/hr and altitude drops from 10,000 to 5000 m.

MiG-21F-13 aircraft longitudinal controllability is characterized by relatively little force on the stick and small angles of stabilizer deflection. Fig.30 displays the graphs of forces acting on the control stick of the MiG-21F aircraft performing straight flight at aftermarking p[illegible] setting with balance within 30 - 35 per cent MAC limits depending upon M-number and altitude of flight. Figs 31 and 32 show that speed increase from M = 0.8 to M = 2 at 15,000 m will necessitate stabilizer deflection angle change by 0.5 - 1.0° only which entails the change of force on the stick by 1.5 kg. The aircraft does not tend to tumbling during acceleration and the condition of level flight is maintained easily.

As the balancing curves in Figs 31 and 32 indicate increase of altitude at constant M-number requires greater deflection of the stabilizer and, consequently, greater force on the stick. This will entail increase of angle of attack when flying at high altitudes.

Fig.32 shows that at augmentation of altitude from 10,000 to 15,000 m, the force exerted on the stick at M = 1.8 increases by 2 kg, approximately.

Lateral stability and controllability of aircraft. Lateral stability of the aircraft implies aircraft ability to recover the initial flight conditions without tank and slip (or with initial angles of tank and slip). Lateral stability is provided for by correct relation between cross and directional stability. If one of them is excessive, the aircraft will become unstable in lateral respect, i.e., it may develop oscillations or spiral instability.

In case of the MiG-21F-13 aircraft the cross-to-directional stability ratio is conceived to make the aircraft s[illegible]

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and well controlled in lateral respect at all flying speeds and altitudes. The ventral fuel tank deteriorates aircraft cross stability. When the aircraft is flying at supersonic speeds with M-numbers exceeding 1.4, its directional stability somewhat deteriorates which is partially due to decrease in efficiency of the vertical empennage because of its lift coefficient reduction and because of vertical empennage shading by the fuselage and wing, particularly when the aircraft is flying with high angles of attack.

Deterioration of directional stability, when the aircraft is carrying a ventral tank is due to the fact that the greater part of the tank is ahead of the aircraft centre of gravity, therefore, when aircraft yawings occur, the resultant lateral aerodynamic force of the tank will pass before the aircraft centre of gravity and will create, in relation to the centre of gravity, a moment which leads to increase of aircraft yawings.

With altitude increase, cross and directional stability of the aircraft deteriorates mainly due to decrease of damping moments of the wing and vertical empennage caused by air density diminution.

Lateral controllability of the aircraft consists of interconnected cross and directional controllability.

Cross controllability is usually characterized by value of angular velocity of aircraft rotation around its longitudinal axis at a given aileron deflection depending upon flying speed or M-number, and by forces exerted on the stick at a given angular velocity of aircraft rotation.

Angular velocity of aircraft motion around its longitudinal axis depends on aircraft flying speed, deflection angle of ailerons and wing span. If aileron deflection angle is constant, augmentation of flying speed at first increases and then decreases aircraft angular velocity, as is indicated in Fig.33, which displays dependence of angular velocity of MiG-21-13 aircraft movement around its longitudinal axis

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($d\omega_x$) upon M-number and altitude at constant deflection of the ailerons ($\Delta\delta^c_{aller}$). The figure shows that with M-number increase and at constant deflection of the ailerons, angular velocity of the aircraft is progressing up to M = 1.8 at 4000 - 5000 m. and up to M = 1.15 at 11,000 m., then it starts to drop. Diminution of angular velocity of rotation is due to aileron efficiency deterioration which is the result of air compressibility and wing strain effect at low altitudes and mainly of air compressibility effect at high altitudes.

Forces on the stick during deflection of the ailerons depend only on the value of deflection as the system of aileron control incorporates irreversible hydraulic amplifier and spring loaded mechanisms.

Therefore, as the deflected ailerons produce constant angular speed of rotation, then with flying speed growth it will be necessary to reduce aileron deflection angle which will result in decrease of the forces exerted on the stick.

In case of the MiG-21 -15 aircraft, to create constant angular velocity of rotation it is necessary to diminish the forces on the stick when M-number increases up to 1.8 at 4000 - 5000 m. and up to 1.15 at 11,000 m., and to augment them with further increase of M-number, as aileron efficiency deteriorates.

After the aileron boosters cut off, the load on the stick during deflection increases as it becomes necessary to overcome aerodynamic load emanating from the ailerons. With the aileron boosters inoperative, flying is limited to IAS about 1100 km/hr and M = 1.4. At high flying speeds and M-numbers the pilot's efforts are usually not sufficient to keep the aircraft from possible banking.

As is shown in Fig.33, altitude increase entails diminution of maximum angular velocity of aircraft roll, as the efficiency of the ailerons deteriorates. Thus, for example if at 4000 - 5000 m. maximum angular velocity of rotation is

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equal to 0.4 $\frac{\text{rad/sec.}}{\text{degree}}$, at 11,000 m. it will be only 0.2 $\frac{\text{rad/sec.}}{\text{degree}}$.

MiG-21 -13 aircraft lateral controllability depending on rudder deflection is largely explained by the fact that the rudder control system does not incorporate a hydraulic amplifier. It is usually characterized by rudder deflection angle values and efforts on the pedals necessary to produce 1° angle of bank. The latter is called the bank angle pedal effort gradient. The MiG-21 -13 aircraft requires much greater bank angle pedal effort at supersonic speeds than at subsonic ones, which is partly due to reduction of rudder efficiency at supersonic speeds as a result of air compressibility effect. Thus, for instance, bank angle pedal effort gradient at M = 0.8 is 2 - 2.5 kg, while at M = 1.5 it will be 10 kg per each degree of bank angle. Due to this reason aircraft control in lateral respect at supersonic speeds is effected by the ailerons only. The aircraft bank response to rudder operation at all ranges of altitudes and M-numbers is direct.

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Chapter III

INDIVIDUAL FLYING TECHNIQUE

Training of personnel on the MiG-21 aircraft consists of ground training and flight training aimed at perfection of individual flying technique.

The purpose of ground training is to provide for successful execution of flights. It comprises theoretical coaching, cockpit training and pilot's practice in starting, taxiing and stopping the engine.

Within the overall system of flight training, individual flying technique is a primary step to train the pilot for group flying, combat procedures and for adverse weather conditions flights in the daytime and at night.

Individual flying technique training is carried out in sequence stipulated by training syllabus.

Preparation and Organization of Flight Solo Flight

MiG-21 aircraft operation and flying have a number of features which must be taken into account during solo flight and during advanced training of flight personnel.

These features are originated by:

(a) installation of new equipment and instruments in the cockpit and somewhat different, as compared with other aircraft cockpits, layout of flight and navigation instruments;

(b) high take-off and landing angles;

(c) introduction of brake system into the nose wheel (in addition to main wheel brake system), which allows to cut down landing run;

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(d) introduction of the control stick load adjustment automatic unit into the stabilizer control system, which facilitates aircraft control at speed and altitude variations;

(e) high efficiency of the ailerons at subsonic speeds; this factor, though not aggravating flying in good weather conditions, requires closer attention to be paid to maintain lateral balancing while flying in clouds and at night.

Besides, the aircraft is characteristic of noise, which might not have been experienced by the pilot and which occurs momentarily when flight condition is changed and the air intake cone is displaced. A high pitch noise is usually heard in the aircraft nose section when the cone moves to its first position (M-number = 1.5). When the speed is augmented and the cone moves to its extreme position (M = 1.9), the pitch of the noise becomes higher.

Noteworthy features of the aircraft flying are discussed in the following Paragraphs of this Chapter.

The above mentioned features and lack of two-seat aircraft of this type induce the instructing pilot to coach the trainee more thoroughly prior to execution of flight mission, particularly during initial period of training.

As it is impossible to check handling of cockpit equipment by the trainee in flight, it is advisable to substitute this check by cockpit training on the ground.

Systematic cockpit training is of paramount importance, as it greatly influences flight mission success and safety of flying.

The purpose of cockpit training is to make handling of levers, cocks, switches and other elements of controls in normal flight (successively according to flight phases) and in emergency, an automatic performance.

It is necessary to achieve faultless interpretation of light panels and signal lights to determine accurate and timely operation of air intake automatic unit, aircraft and engine and systems.

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Prior to the first solo flight on the [illegible]-21-1b [illegible] flight technique of the trainee is checked, if necessary, on the [illegible] two-seat trainer in the sector.

Pre-flight preparation of the trainee is carried out as follows. At the beginning of the flying day the trainee is coached in the cockpit and his attention is drawn to the projection of the aircraft nose on the horizon at take-off. At normal posture, as indicated in Fig.34, the pilot sees about 1/3 of fuselage nose section. After that the trainee starts and tests the engine, and then practices in taxiing and discontinued take-off under supervision of the instructing pilot or ground engineer.

Taxiing and discontinued take-off are performed in the following order. After making sure that the engine and brakes operate normally, the trainee releases nose wheel brakes, checks flaps up position, closes the canopy, seals the cockpit and requests clearance of the traffic control officer to taxi to the runway. After being cleared, he starts taxiing. While taxiing, the trainee checks the brakes. The aircraft is stable on taxiing and does not tend to rock or yaw.

While taxiing on a concrete runway at idle speed the aircraft experiences speed growth, therefore, the pilot must occasionally apply brakes.

If it is necessary to make a turn, the aircraft must be slowed down as performance of a turn at high speed is accompanied by side skidding, particularly when the runway is slippery. Turns should be executed with the help of brakes, steep turns from standstill must be avoided as they exert great loads on the main landing gear struts. It should be borne in mind, when using brakes, that in case of disc-type brakes, the braking effect somewhat lags behind the system pressure growth. Therefore, although the pilot does not feel the braking effect when the brake actuator has been pressed, he should not hurry with pressing the actuator further down, as it will result in [illegible] braking.

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After entering the runway, the pilot taxies straight ahead for 20 - 30 m. to align the aircraft with the runway, turns the nose wheel brake on, extends flaps and requests clearance for discontinued take-off.

The nose wheel brake is conceived to reduce aircraft roll length during discontinued take-off and landing.

On getting clearance the trainee, keeping the brake pedals pressed full down, increases engine r.p.m. to 80 - 90 per cent on the low-pressure rotor indicator, turns his eyes to the cowl-horizon direction, releases brakes and executes roll for 300 - 400 m.; then he smoothly retards the throttle lever to idle speed and continues roll using brakes and maintaining direction of roll by means of brakes.

After the aircraft has come to standstill, the pilot retracts the flaps, turns the nose wheel brake off and returns to the parking place.

While performing taxiing and discontinued take-off the pilot consolidates the habits acquired during cockpit training in handling levers in their strict sequence corresponding to pilot's actions before taxiing, take-off and accomplishment of landing run.

After taxiing and discontinued take-off have been efficiently executed, the trainee can be allowed to perform solo flight.

The first solo flight is carried out over the airfield at 1000 - 3000 m. After take-off the pilot climbs to an assigned altitude and performs one or two circuits at this altitude ; then, the altitude is decreased to 500 m. and the pilot accomplishes two more circuits over the airfield.

The second circuit is converted into approach for landing when the aircraft has not more than 1100 lit. of fuel left. A greater amount of fuel and, consequently, greater gross weight may complicate landing.

In units where conversion courses on the MiG-21-15 aircraft are held for the first time, it is advisable to [illegible]

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for demonstration circuit flights of experienced instructing pilots.

Circuit Flying

Before flight, the pilot plans his actions in handling cockpit equipment at various phases of flight beginning from starting the engine and ending with parking, estimates weather conditions, gets acquainted with take-off procedure, estimates airfield condition and aerial situation in the airfield area.

After receiving and inspecting the aircraft, the pilot enters the cockpit and adjusts the seat so, that he would be able to see 1/3 of fuselage nose section.

After inspecting the cockpit and making sure that the cockpit is free of unrelated articles, the pilot starts and runs the engine for testing. When engine operation control indicators and aircraft system operation indicators read normally, the pilot closes all the circuit breakers that are necessary for circuit flight and requests clearance for taxiing. After getting clearance from the air traffic control, the pilot closes and seals the canopy, turns the nose wheel brake off, lowers the flaps, locks the safety belts and starts taxiing, keeping in mind taxiing procedure discussed above.

In reaching holding position, the pilot makes sure that the runway is clear and there is no aircraft on final, then requests clearance to line up. After being cleared to line up he taxies the aircraft to take-off position and rolls 5 - 10 along the runway to make the nose wheel symmetrical with aircraft axis. If the latter is not done, the pilot will experience difficulties to maintain directional control during the first half of take-off run. Before take-off the nose wheel brake is turned on and the landing gear control lever is unlocked.

For the purpose of efficient adoption of pre-take-off procedure, the pilot is advised to report the above indications

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actions to the air traffic control officer during the first flights.

Depending upon fuel supply and external suspensions, take-off is performed at full thrust or with afterburning power settings.

Full thrust power take-off. After being cleared for take-off, the pilot applies full brakes and smoothly increases engine r.p.m. to maximum. When the engine reaches 1[illegible] per cent r.p.m. on low-pressure rotor indicator, the brakes are released and the aircraft begins to roll.

During the initial roll, directional control is maintained by means of brakes. Availability of nose wheel brake and narrow tread makes the aircraft sluggish in responding to directional control error corrections at take-off, particularly during the initial roll.

After sufficient speed is obtained directional control is maintained with the rudder, which becomes sufficiently effective at 14[illegible] - 15[illegible] km/hr. The aircraft is directionally stable on take-off roll and does not tend to turn.

At the beginning of take-off roll the control stick is kept neutral. After reaching 200 km/hr the pilot smoothly applies back pressure to the stick and raises the nose wheel off the runway.

During first flights to forestall the aircraft false keel dragging, the nose wheel is raised to position where the aircraft nose will be 5 - 7 cm. short of the horizon line, as is shown in Fig.35.

During the following flights the nose wheel is raised until the aircraft nose reaches the horizon line. This attitude of the aircraft is maintained to the moment of unstick. At this time the pilot is looking forward through the windshield.

Nose-high attitude of the aircraft results in low unstick speed and may lead to false keel dragging. Nose-low attitude results in high unstick speed and increases take-off roll length. Aircraft unstick speed is 31[illegible] - 315 km/hr.

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After unstick the pilot turns his eyes to the [illegible] watches it through the side window. Maintenance of [illegible] climbing is effected alongside with gradual accelerating.

The aircraft climbs smoothly and builds up speed at the same time.

As was indicated above, high efficiency of the ailerons is a characteristic feature of the aircraft. Therefore, the unstick the bank will be corrected by intermittent aileron movements, particularly at ground level.

At 1[illegible] - 15 m. the pilot retracts the gears. The speed must not exceed 55[illegible] km/hr when the landing gears are being retracted. Time for gears retraction is [illegible] - 6 sec. and it is subject to increase with speed growth. At a speed higher than the indicated one the landing gears may fail to retract.

After the landing gear lever has been moved to position UP (ВВЕРХ), the process of retraction is checked by signal lights and by hydraulic system pressure. When the hydraulic system indicates full pressure, the landing gear lever will set neutral. If one of the landing gear signal lights does illuminate, the speed should be cut down to 5[illegible] - 55 km/hr and if even at this speed the light does not go on, the pilot must discontinue the mission and land the aircraft.

The flaps are retracted at 1[illegible] - 15[illegible] m. The aircraft experiences slight sagging when the flaps are retracted though the pilot almost does not feel it.

While taking-off with a drop tank, the nose wheel is to be raised at 21[illegible] - 22[illegible] km/hr, take-off run length, at that, somewhat increases. Otherwise, take-off with a drop tank or one wing missile load is similar to the described one.

<u>Take-off at afterburning power setting.</u> When taking off at afterburning power setting, proceed as follows: apply the brakes and increase engine r.p.m. to maximum. After making sure that the engine has picked up full thrust power, move engine control lever to position AUGMENTED (ФОРСАЖ).

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Afterburning power sets in during 5 - 8 sec. and is manifested by an impact, after which the pilot releases the brakes. As the time and take-off run length of afterburning power take-off are lesser than those of full thrust power take-off, the pilot's actions must be highly-efficient and timely.

As the speed builds up rapidly during this take-off and stabilizer efficiency increases faster, the usual procedure of control stick handling the pilot got used to when taking off at full thrust power, may lead, if applied, in this case, to false keel dragging. Therefore, special attention should be paid to raising the nose wheel to take-off position and maintaining it in this position until unstick. After unstick the aircraft picks up speed rapidly and climbs with high pitch angle.

Climbing and flight planning. After retraction of the landing gear and flaps, the speed of the aircraft noticeably increases, therefore, it is necessary to reduce engine r.p.m. to normal rated ones, setting climbing speed of 5[illegible] km/hr.

After assuming steady climbing attitude at 150 - 2[illegible] m. the pilot orients himself and starts executing a turn.

Crosswind and downwind leg turns are executed [illegible] maneuver with 1[illegible]° bank at climbing speed of 5[illegible] km/hr.

After traffic pattern altitude is reached, [illegible] is made without climbing. Check points for [illegible] are runway direction and compass indicator [illegible] and a landing reciprocal course.

The distance between the aircraft on traffic pattern must not be less than 15.0 - 18.0 m.

The landing gears are lowered at 500 km/hr after the landing Tee is passed. Landing gear extension is checked by signal lights and hydraulic system pressure. The landing gear lever remains in DOWN (ЗАКР.ВЫП) position until the aircraft is parked. After extending the gears the pilot sets 450 km/hr speed (low-pressure rotor r.p.m. - 80 - 85 per cent) and requests clearance for landing. When flying with [illegible]

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the aircraft experiences slight buffeting and impacts are felt on the pedals and control stick.

Flight circuit diagram is given in Fig.30.

Commencement of base leg turn is determined by angle of view to the landing marks. When flight planning is normal, the landing Tee will be projected at an angle of 60 - 65°, while the radio compass indicator will read about [illegible]. The angle of the base leg turn will be 1[illegible] - 11[illegible].

The turn and gliding descent prior to flaps extension is executed at 45[illegible] km/hr.

The flaps are lowered on the base leg. Flaps extension is checked by signal lights. The hand is kept on the flaps control panel until the flaps are full down. In case of stiff banking of the aircraft, the flaps must be raised immediately.

Flaps extension is accompanied by occurrence of slight pitching moment which is easily counteracted by the control stick. After the flaps are lowered, the speed is reduced to 4[illegible] km/hr (engine r.p.m. on low-pressure rotor indicator - 75 - 8[illegible] per cent).

The [illegible]-3[illegible] automatic unit position is checked when speed drops to 42[illegible] km/hr. The pointer of the [illegible] indicator must in extreme left position, which corresponds to "large arm" the T-4 light panel should read STABILIZER FOR LANDING ([illegible]).

If the T-4 light panel inscription does not illuminate or the pointer is not full left, the pilot should go around and then, turn the [illegible] rod to the "large arm" position manually; for this purpose selector switch [illegible] (ABZ[illegible]) is turned to position MANUAL ([illegible]), the pressure switch - to position LOW SPEED ([illegible]) and kept in this position until the T-4 light panel illuminates and the pointer of the indicator travels to the extreme left position.

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Note: If it is impossible to set the AVJ-53 automatic unit in the "large arm" position, landing will be executed at any position of the AVJ-53 unit, though the landing, when the AVJ-53 unit is in the "small arm" position, will require greater attention and accurate actions. It must be borne in mind that in this case stabilizer travel margin decreases by 50 per cent and the load on the control stick increases by 2 - 2.5 times (in the order of 20 - 25 kg).

In this case it is necessary to establish lower glide angle of approach and augment speed by 20 - 30 km/hr. Touch-down speed will be higher than usual. When landing with the AVJ-53 unit being in the "small arm" position, it is necessary to avoid errors as the decreased margin of stabilizer travel complicates their correction.

Final turn - final approach and judgement. Final turn is executed at 350 - 400 m. and 400 - 420 km/hr speed when the angle between the runway line and the line of view to the landing Tee is 20 - 25°.

Commencement of the final turn depends upon wind direction. In case of left hand traffic pattern and port crosswind, the final turn must commence somewhat earlier, while starboard crosswind demands somewhat delayed entrance into the turn. In all cases, however, the final turn is to be executed over the point which is at a constant distance from the landing Tee.

The aircraft is recovered from the final turn at an altitude not lower than 300 m. During execution of the final turn the pilot verifies his judgement with the help of the runway. If final approach is faulty, it will be corrected by coordinated turns of 15°. The pilot must go around, if the approach error is too great. Approach directional judgement should be verified prior to passing LIN. When on final, the pilot establishes a suitable glide angle to direct the aircraft to the point of flare-out.

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Flare-out commencement point is 1 [illegible] km. away from the approach end of the runway (Fig.37). At a normal glide angle engine r.p.m. will be within 6 - 7 per cent on 1 [illegible] rotor indicator.

Glide speed gradually decreases from 4[illegible] km/hr, after the final turn, to 34[illegible] - 33[illegible] km/hr, at the beginning of flare-out, when flying without external load, and to 35 - 34 km/hr when missiles are carried.

The most characteristic error, pilots make at gliding, consists in their tendency to set 34 - 33 km/hr speed right after the final turn which leads to gliding with high pitch angles. Premature increase of pitch angle leads to deterioration of runway observation and supervision of aircraft [illegible] and complicates determination of flare-out commencement altitude. Premature or abrupt reduction of throttle during flare-out procedure entails loss of speed (due to high drag, and aircraft is flown at high angles of attack) and intensive descent of the aircraft. Pilot's attempt to reduce rate of descent by applying back pressure to the stick does not [illegible] effective - the aircraft continues descending in the [illegible] mushing. The landing will be with a "flop", the nose will be lowered abruptly and the nose wheel will experience great [illegible]. This will be the case of undershoot. Aircraft's floating [illegible] the runway is so short that it seems as if the aircraft [illegible] down at a point where the pilot cuts the throttle down.

When great pitch angles are imparted to the aircraft prematurely and during prolonged reapplications of power at high angles of attack, the pilot maintaining 34 - 33 km/hr (at the expense of higher r.p.m.), should fly over the runway and, only after reaching the runway, should smoothly reduce engine r.p.m. arranging it so that the power is reduced according to aircraft descent and is fully cut-off at the moment of touchdown. Steep glide path also complicates approach for [illegible]ment and landing.

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Steep glide path makes it difficult for the pilot to set required gliding speed, and gliding proper is performed at high rate of descent.

This factor complicates determination of flare-out commencement altitude; besides, during round-out procedure it will be a problem to find out required rate of application back pressure to the stick to terminate flare-out at 1 m. If the pilot rounds out too energetically, it may happen that flare-out will be too high above the ground level and due to this there will be loss of speed. As the pilot is unable to set high r.p.m. in short time and forestall mushing, this error will be difficult to correct.

In case of delayed rate of application of back pressure to the stick, rate of descent will decrease slowly. When the pilot becomes aware of this phenomenon while approaching the ground, he will have to pull harder on the stick (at a certain moment of flare-out). Due to inertness, the aircraft will continue to descend for some time, though angle of attack is increased, and it may happen that the aircraft will touch the ground roughly with its wheels at the moment of flare-out.

The judgement will be correct if the pilot plans to establish such a glide path on final as to overfly LIM at 100 m.

This glide path offers the best conditions for judgement and landing. It is most applicable for flights at night and in adverse weather conditions in the daytime.

Landing. To determine the moment of round-out commencement, the pilot, at an altitude of 25 - 30 m., shifts his eyes to the ground left and forward at an angle of 15 - 20° and down at an angle of 15 - 20°. Prior to round-out he makes sure that the gliding speed is 340 - 330 km/hr or 350 - 340 km/hr if the missiles are carried.

At 8 - 10 m. by applying smooth and coordinated back pressure to the stick the pilot decreases gliding angle with an aim to bring the aircraft to the ground level at a height

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not exceeding 1 [illegible] In case of high flare-out, the pilot g[illegible] sometimes back pressure and reapplies it later c[illegible] with speed decrease and aircraft descent to execute a normal landing.

An error, entailing aircraft ballooning after back pressure has been applied to the stick, must be rectified in accordance with the character of ballooning.

When ballooning occurs at high speed, it is necessary discontinue further ascent of the aircraft by applying [illegible] and attributed forward pressure and on approaching the gr[illegible] reapply back pressure smoothly and execute a normal l[illegible]

If ballooning occurs at normal or somewhat lower speed the pilot at the moment of aircraft ascent should hold the stick in the position it has reached at the moment of ballooning. On approaching the ground, the pilot applies smooth but brisk back pressure to the stick and lands touching the main wheels first. If judgement is accurate and approach to flare-out commencement, altitude is made at 34[illegible] - 35[illegible] km/hr, the throttle is closed smoothly with commencement of flare-out. The engine control lever is moved aft at a rate to obtain [illegible] speed at the end of flare-out (at [illegible].75 - 1 m).

Floating is executed with gradual descent of the aircraft. During this procedure the pilot using the control stick, establishes high angles of attack to land the aircraft on the main wheels without pancaking (with the stick almost full b[illegible]

Insufficient application of back pressure to the stick leads to touchdown at high speed which increases landing length.

During floating pilot's eyes must be directed 2[illegible] - 25° left and 4[illegible] - 5[illegible] m. forward. It is not advisable to watch the ground straight ahead through the windshield as nose-high attitude of the aircraft complicates judgement of distance to the ground.

After landing the stick is held in the position it has reached at the moment of touchdown, the pilot looking in the same direction as during floating.

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Landing with one sided missile load is similar to the described one.

After 150 - 200 m. roll the pilot lowers the nose wheel smoothly, turns his eyes to look forward and begins to apply brakes. Abrupt fore movement of the stick leads to abrupt lowering of the nose wheel and to great impact loads on the nose wheel strut. Prolonged holding off of the nose wheel increases landing roll length as application of brakes is delayed.

For the purpose of decreasing landing roll length, full brakes will be applied right after lowering of the nose wheel and at a speed not exceeding 280 km/hr, the brake chute will be ejected.

In case of the main braking system failure, braking is effected by means of the emergency system lever.

The emergency braking lever should be operated smoothly to avoid tire damage.

The brake chute is jettisoned after the aircraft clears the runway. If landing is executed on a metallic runway, the brake chute is jettisoned on the runway prior to complete stoppage of the aircraft at a speed of 30 - 40 km/hr.

Before clearing the runway the pilot raises the flaps and turns the nose wheel brake off. The aircraft taxies from the runway by using its insignificant inertia. The pilot taxies to the parking place with the canopy closed.

Aircraft inertia should be used to clear the runway in case of brakes failure.

On approaching refueling facilities or aircraft parking place, the pilot must cut down taxiing speed to about 5 km/hr and, observing safety precautions, enter the parking place. After parking the aircraft, he cuts the engine off, unreels the cockpit and opens the canopy. The pilot is allowed to leave the cockpit after the ground engineer has fixed safety pins in the cockpit.

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Go-around Procedure

Go-around procedure can be carried out from any altitude including the altitude of floating. After the pilot has made a decision to go around, he increases engine r.p.m. to maximum. While going around from an altitude below 5 m. it is necessary to increase engine r.p.m. and pick up speed, keeping the ground in sight all the time. On attaining 3[illegible] - 37[illegible] km the aircraft assumes climbing attitude and the landing gear are retracted.

After making sure that the gears are up and hydraulic system pressure increased to 21[illegible] kg/sq.cm. the pilot retracts the flaps at an altitude not lower than 1[illegible] m.

Take-off and Landing on Unpaved Runway

Take-off from even unpaved strips having sufficiently hard surface is similar to take-off from a concrete runway. During taking-off from a strip having rough surface, the aircraft displays tendency to roll and rock. The pilot experiences difficulties in maintaining the aircraft more in take-off attitude due to non-uniform friction of the wheels against the ground.

Take-off run with the nose wheel raised may be necessary by aircraft unstick at low speed with consequent rough touch downs with main wheels, therefore, the pilot is not advised to use the control stick for checking aircraft roll and rock. It is recommended to raise the nose wheel at a speed exceeding the prescribed one by 1[illegible] - 20 km/hr. Correspondingly, unpaved runway take-off run length will increase as compared with paved runway take-off run length.

Landing on an unpaved runway is similar to that on a concrete runway. When landing on a strip with rough surface the pilot plans to touch the main wheels first and keeps the nose wheel raised as long as possible.

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If the nose wheel is lowered early, when progressive speed is still high, it will experience great loads when it bumps against rough surface. At the moment, the nose wheel is lowered the pilot commences to use brakes smoothly. Aircraft landing run on an unpaved runway is considerably shorter than that on a concrete runway. The aircraft experiences rocking and rolling on landing run.

Crosswind Landing

During crosswind landing the pilot plans to fly the aircraft so as to align its flight path with the centre line of the runway.

Landing in a crosswind up to 15 m./sec. velocity and rectangular to the runway presents no special problem.

Aircraft drift should be corrected by upwind wing low attitude (a slip) with a bank up to 1[illegible] - 15°.

If the crosswind is stronger than 15 m./sec. drift is corrected by combination of slip and crab.

At the end of floating the slip is gradually diminished and at the moment of touchdown is eliminated completely, the rudals being neutral; touchdown is accomplished on both main wheels.

After touchdown the pilot smoothly lowers the nose wheel to improve directional stability of the aircraft on landing roll.

Flapless Landing

Flapless landing has some features as compared with normal landing.

Final approach during flapless landing is longer than during normal landing. Taking into account the fact that [illegible] in flying with flaps up, displacement [illegible]

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the pilot is advised to extend air brakes prior to [illegible] final turn. Gliding and flare-out are carried out at 35[illegible] - 36[illegible] km/hr.

Flare-out commencement point is planned at a longer distance from the approach end of the runway than [illegible] down landing.

Touchdown, in this case, is usually accomplished at [illegible] speed.

After lowering the nose wheel and at a speed not exceeding 28[illegible] km/hr, the pilot ejects the brake chute and applies brakes.

Noteworthy features of fighter flying

The MiG-21-13 aircraft is conceived to perform all aerobatic maneuvers.

While performing aerobatic flights, however, the MiG aircraft has the following specific features.

1. Aircraft attitude relative to the horizon is somewhat difficult to determine during performance of vertical aerobatic maneuvers. This feature arises from the fact that firstly, the pilot has in sight only a small part of aircraft "nose" due to its rake and, secondly, pronounced sweep of the wing and considerable aft displacement of the [illegible] are limiting pilot's possibility to position the aircraft using the natural horizon line, particularly when the pilot is clad in a high altitude pressure suit. Therefore, the pilot resorts to artificial horizon check for determining aircraft attitude.

2. Vertical aerobatic maneuvers rapid and [illegible] to high speeds the maneuvers are entered at.

3. All aerobatic flying is performed with aircraft balanced at V_{IAS} = 800 km/hr and H = 6[illegible] m. When the aircraft is accelerated to V_{IAS} = 750 ±10[illegible] km/hr, [illegible] stick are close to zero, and at V_{IAS} = 85[illegible] - 1,2[illegible] stick experiences insignificant drag forces.

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4. Execution of acrobatic maneuvers in vertical plane at speeds corresponding to M = 1 and higher requires greater deflection angles of the control stick.

5. Acrobatic flying with great G-loads at medium altitudes and with relatively small G-loads at high altitudes is accompanied by occurrence of characteristic warning shaking vibration and by wing rocking, if the stick is pulled further. In this case further application of back pressure to the stick must be discontinued till warning shaking vibration and wing rockings disappear.

6. At altitudes exceeding 1[illegible] km. with afterburner on at a speed of M = 1.2 and above, a turn can be executed with the stick almost full back, and the aircraft will not experience warning shaking vibration and wing rockings.

7. During execution of vertical acrobatic maneuvers at full thrust power setting, the aircraft rapidly looses its speed while approaching top point; this factor requires accurate and coordinated handling of the controls.

8. The pilot is to wear pressurized anti-G suit and helmet, when he is embarking on a mission to be carried out at high speeds and altitudes.

Turn

Turn can be executed at all operating altitudes and speeds.

For training purposes, the most advantageous turn will be executed with 6[illegible]° bank at IAS 55[illegible] - 75[illegible] km/hr and altitudes below 6[illegible] m. when the engine is operating at normal rated thrust and full thrust power settings. For execution of a turn at afterburning power setting and at altitudes above 6[illegible] m., bank up to 75° is used.

Prior to making a turn the pilot selects turn [illegible] recovery directions, sets a required speed and the [illegible] turn with the help of smooth [illegible]

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controls. Engine thrust will grow with bank and angular rotation increase. If the turn is properly executed, the lower angle of the right light shield will slide along the [illegible] line. Bank, speed and altitude are checked by artificial horizon, speed, rate of climb and altimeter indicators. Any in the given parameters are corrected by changing bank and angular rotation. If excessive back pressure is applied to stick, the aircraft will experience warning shaking vibration and further increase of angular rotation will entail aircraft rocking. To forestall aircraft stalling the pilot should diminish the force on the stick by moving it forward until aircraft rocking stops.

Warning shaking vibration occurs when G-load reaches 4 - 4.5. It must be remembered that shaking vibration has considerably lower critical C_y, therefore shaking vibration does not mean the beginning of aircraft stall.

When the aircraft has 2 - 3° to go to enter reported direction, which the pilot determines with the help of the check point and compass, it is necessary to start recovering the aircraft from the turn by coordinated handling of the stick and pedals and simultaneous reduction of engine r.p.m. Engine r.p.m. reduction must be planned so that aircraft recovery is not accompanied by speed change. Execution of left turn is similar to that of right turn. The pilot checks the condition in turn on artificial horizon, rate of climb, speed and altimeter indicators.

The pilot is trained to execute turns first at normal rated and full thrust power settings and then at afterburner power setting. Full thrust power setting turn at altitudes above 6,000 m. and with a bank exceeding 60° is accompanied speed loss.

Turn is stable when executed at afterburning power setting at 11,000 - 12,000 m. and M-numbers equal to 1.2 - 1.4 with 60° bank and G - 2.5 - 3. When G increases to 3.5 - 3.8, speed will be lost in turn (M-number drops from 1.4 to

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The distinguishing feature of turns executed at altitudes above 10,000 m. and M > 1.2 is that the control stick is moved to almost full aft position, and the aircraft does not yet experience shaking vibration and rocking.

It must be borne in mind that decrease of speed to M below 1.1 entails abrupt augmentation of angular rotation and assumption of high angles of attack by the aircraft due to stabilizer efficiency increase. In these cases the pilot should somewhat release back stick pressure.

Table 7 below gives characteristics of steady turns most advantageous as to time factor.

Table 7

Parameters	Power setting		
	maximum		augmented
	H = 5[illegible] m	H = 10,[illegible] m	H = 12,[illegible] m.
Speed V_{TAS}, km/hr	9[illegible]	9[illegible]	1[illegible]
Turn duration, sec.	5[illegible]	1[illegible]	85
Turn radius, m.	2[illegible]	4[illegible]	4[illegible]
G-load	3.2	1.8	2.3

Procedure of turn execution when the aircraft is carrying a drop tank is practically the same as in case when the aircraft flies without it. The procedure of lazy eight execution is similar to that of turn execution. Recovery from the turn of one direction and entrance into the turn of the other direction are accomplished by means of continuous coordinated movements of the stick and pedals without changing engine control lever position. Due to tank and G-load changing, the speed and altitude are maintained constant during the whole maneuver.

Characteristic errors in turn execution are as follows:

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1. Excessive back stick pressure [illegible] shaking vibration and then by aircraft rocking. This [illegible] is corrected by decreasing angular rotation by slightly releasing back stick pressure.

2. Required altitude and speed are not properly [illegible]. The error is corrected by changing bank and angular rotation.

If during execution of turn, altitude and speed [illegible] deviate greatly from the prescribed ones, the maneuver [illegible] to discontinued. The aircraft assumes level flight attitude and then the maneuver is started from the beginning.

Chandelle

Chandelle is executed at full thrust and [illegible] power settings and at speeds not exceeding [illegible] speed of level flight. For training purposes it is [illegible] at medium and high altitudes and in stratosphere at [illegible] entering speeds not exceeding a speed maximum permissible [illegible] the given altitude. Prior to entering the maneuver the pilot must accelerate the aircraft. The speed is picked up during shallow bank (up to 1[illegible] - 15°) descent with the engine [illegible] ing at full thrust power setting. After the given speed is obtained the aircraft assumes level flight attitude. Then moving the stick aft and to the direction of the required [illegible] with simultaneous slight deflection of the rudder to the same direction, the pilot starts climbing on steep upward spiral.

Initial bank should not exceed 1[illegible] - 15°, while the bank at the second half of the turn must be within 65 - 7[illegible]° [illegible].

During the initial stage the pilot experiences effects of considerable dragging forces which gradually diminish after IAS drops below 7[illegible] - 600 km/hr. This enables the pilot to rotate the aircraft more vigorously increasing G-load to 4.5 - 5. Natural horizon projection line divides the cockpit

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port (starboard) into two halves. After the aircraft completes 180 - 190° turn and speed drops to 5[illegible] km/hr, the bank and angle of ascent are gradually decreased. This is effected by simultaneous coordinated movement of the control stick forward and diagonally to the direction opposite to the turn and slight deflection of the rudder with the aim to recover the aircraft from the turn at exactly 180° and at a speed not less than [illegible]0 km/hr. Recovery direction is checked on compass indicator. If the recovery is properly executed, the horizon line will be projected at the left (right) edge of the sighting head of the ASP-3NM sight.

The procedure of execution of right and left chandelles is the same at full thrust power setting as at afterburning power setting.

Chandelle executed at afterburning power setting is distinguished by high rates of climb, bigger gains in altitude and more prolonged G-loads. Thus, entering the maneuver at [illegible] m. and V_{IAS} = 1[illegible] km/hr the aircraft climbs to about [illegible] m. developing maximum rate of climb of 3[illegible] m/sec. during maneuver while during execution of chandelle at full thrust power setting from the same altitude and at the same maneuvering speed (V_{IAS} = 1[illegible] km/hr) the aircraft climbs to [illegible] - 1[illegible] m. and develops maximum rate of climb of 1[illegible] - [illegible] m/sec.

Afterburning power chandelle is characterized by considerable dragging forces on the stick, when the aircraft enters maneuver, and by slower rotation along the longitudinal axis. To decrease dragging forces at the beginning of the maneuver and to augment angular speed, the pilot is advised to use the damping effect mechanism. During training in execution of this maneuver, special attention should be paid to the procedure of entering the maneuver.

Abrupt (too vigorous) handling of the stick [illegible] the maneuver leads to wandering of the aircraft and [illegible] left rockings. Therefore, the maneuver must be [illegible]

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smoothly with concurrent increase of deflection to 4.5 - 5. In executing chandelles during his first flights, the pilot plan to enter the maneuver at shallow angles of bank and as this facilitates training in execution of the maneuver. High values of climb and bank make it difficult for the pilot to determine attitude of flight. If, during execution of maneuver, the horizon line is out of sight, the pilot can check aircraft attitude on the artificial horizon [illegible].

Characteristic errors in execution of chandelle are as follows:

1. Abrupt (too vigorous) handling of the controls while entering the maneuver. This entails violent vibration and aircraft rocking. The error is corrected by releasing back stick pressure.

2. Steep bank on entering the maneuver with low climb, which leads to little gain of altitude and to [illegible] from the maneuver at high speed.

3. Maneuver recovery is made before or after 180° due to inaccurate coordination and sluggish handling of controls.

4. Maneuver top is attained at low speed. This error be the result of a low speed at which the maneuver is or too vigorous throwing of the aircraft into the maneuver due to which the aircraft assumes high angles of attack and loses its speed prematurely.

Half-roll

Half-roll is executed at altitudes from 5000 m. up to aircraft ceiling with air brakes being in extended or retracted position.

For training purposes, half-rolls are executed at altitudes:

(a) 5000 m. at IAS not exceeding 400 km/hr;
(b) 6000 - 10,000 m. at IAS = 400 - 600 km/hr;
[illegible]

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(c) 12,000 - 14,000 m. at IAS = 4[illegible] - 5[illegible] km/hr;

(d) above 15,000 m. at IAS = 350 - 400 km/hr.

During initial period of training, half-rolls are executed at altitudes from 6000 to 1[illegible],000 m.

Half-roll is entered either from level flight or after establishment of a pitch angle of 1[illegible] - 15°. After getting a given speed, the pilot begins 180° turn around the longitudinal axis by deflecting the control stick in the direction of half-roll and by slightly pressing the pedal. 80 - 3[illegible]° before attaining inverted flight attitude, the pilot puts the controls neutral to stop the aircraft turning. At the same time he moves the engine control lever aft to the idle speed stop. As soon as the aircraft completes 180° turn, the pilot applies back pressure to the stick planning to recover from the dive and assume level flight attitude at IAS = 65[illegible] - 7[illegible] km/hr. To perform the maneuver properly the pilot must avoid both excessive back pressure and sluggish handling of the control stick. In case of excessive back stick pressure, the aircraft assumes high angles of attack which is manifested in [illegible] flicking vibration and later in wing rockings. In this case, it is necessary to retard back pressure on the stick, until vibration and rockings disappear, and then to recover smoothly level flight attitude.

In case of sluggish application of back pressure to the stick, the aircraft enters vertical dive, recovery from which will require great efforts to be applied to the stick. Besides, in this case the aircraft picks up speed rapidly and recovery from half-roll results in great loss of altitude and high G loads at the point of recovery. If the speed builds up rapidly, the pilot must recover the aircraft from the dive by energetic back stick pressure, avoiding shaking vibration and rockings.

When the aircraft is being recovered from the dive, the forces on the control stick will always be [illegible] altitude during execution of half-roll when the [illegible]

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is entered at 6[illegible] - 1[illegible] m. and at 1[illegible] - 4[illegible] - 6[illegible] km is 3000 - 5[illegible] m.

Characteristic errors in execution of half-roll are as follows:

1. Inaccurate 180° turn of the aircraft around its longitudinal axis due to slight residual bank when the maneuver is entered and due to the fact that this bank is not eliminated during execution of half-roll downward leg.

2. Great loss of altitude during half-roll execution which is explained by much too intelligent recovery in downward leg of half-roll path with low G-loads.

3. Excessive back stick pressure during recovery. This error may cause warning shaking vibration, which, if aggravated, may initiate a spin. To correct the error, it is necessary to retard back stick pressure until with the stops.

4. Aircraft turning around its longitudinal axis in downward leg is not checked by the pilot. This can cause the aircraft into a steep spiral to recover from which it is necessary, firstly, to stop the aircraft turning and then recover it from the dive.

Nesterov's Loop

Nesterov's loop is executed at 4000 - 5000 m. when the engine operates at full thrust power setting and at 6[illegible] - 7000 m. when augmented rating is used.

For training purposes, loop is entered at 4000 m. at IAS = 950 - 1000 km/hr with the engine operating at full thrust power setting. Prior to entering the loop, the pilot sets a given speed in level flight and checks the aircraft for bank.

Then by smoothly applying back pressure to the stick the pilot assumes climbing attitude.

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Back stick pressure will be planned so, as to obtain G-load 4.5 - 5 when pitch angle reaches 4 °.

Further handling of the control stick should be calculated to maintain angular velocity nearly constant. While approaching the loop top point, the pilot decreases back pressure on the stick. The aircraft behaves normally if the speed at the loop top point is within 3[illegible] - 4[illegible] km/hr. When back stick pressure is properly applied, IAS at the top point will be 3[illegible].0 - 37[illegible] km/hr, and G-load - 1.[illegible]. After the aircraft drops its nose below the horizon line, the pilot moves the engine control lever aft smoothly to the idle speed stop and sends the aircraft into diving, and then returns to level flight following the same procedure as for execution of half-roll. IAS during dive recovery must be not less than 6[illegible] - 7[illegible] km/hr. From the moment of entering the manoeuver to the loop top point the aircraft gains 35[illegible] m.

The main feature during execution of loop is difficulty in determining attitude of flight as the pilot does not see other wings, or (for a considerable period) natural horizon, while execution of loop takes a relatively long time ([illegible] - 8 sec, are required to reach the top point).

For proper execution of loop the pilot must pay the attention to maintenance of constant angular velocity, should check, if the aircraft is bank clean, and watch [illegible] speed. Angular motion velocity is checked by the [illegible] horizon line "slipping" under the aircraft and by G-load.

In the second half of the loop after the top point is passed, angular motion velocity is determined with the help of ground check points.

Bank is checked by the artificial horizon [illegible] stages of the loop except when pitch angle is [illegible] except vertical dive, as well as by the position of [illegible] horizon, when the latter is in sight.

Special feature of full thrust power loop [illegible] is relatively rapid loss of speed when the aircraft [illegible]

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the top point. Therefore, in this case handling of the control stick must be accurate and coordinated properly. Excessive back stick pressure entails warning shaking vibration and wing rockings. Thus, if loop is executed at 4[illegible] m., heavy vibration occurs when G-load reaches 5.5. Slight retarding back stick pressure eliminates vibration and wing rocking. Sluggish handling of the control stick at the medium stage of the loop is a more dangerous factor, as due to this fact the aircraft reaches the top point at too low speed.

Loop execution at afterburning power setting is similar to that at full thrust power setting, except that in the former case the aircraft may attain the top point at higher IAS (5[illegible] - 55[illegible] km/hr) and in addition, during first half of the loop the aircraft gains more altitude (ΔH = 4[illegible] - 45[illegible] m.). Afterburner is usually turned on in level flight prior to entering the maneuver and is cut off when the nose of the aircraft does not reach top point by 1[illegible] - 15°. If afterburner is cut off at the loop top point, the aircraft enters dive with rapid growth of speed and great loss of altitude while power is reset from afterburning to full thrust and then from full thrust to idle speed.

Characteristic errors in execution of loop are as follows:

1. Loop is executed with excessive back stick pressure. The error is manifested in warning vibration and wing rocking and is corrected by retarding back stick pressure.

2. The aircraft reaches the loop top point at low speed. This error is the result of sluggish handling of the control stick at the medium stage of the loop or because the aircraft is entered at an altitude which does not provide for [illegible] of the loop. To forestall this error, the pilot, during his first flights must enter the loop at V_{IAS} = 1[illegible] km/hr with not maximum but 97 per cent r.p.m. with the purpose to add thrust by increasing r.p.m. to 100 per cent when speed of upper leg of the loop, becomes comparatively low. At the time the pilot should discontinue back stick pressure and

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the aircraft from banking. The throttle is reduced after the speed is 45[illegible] km/hr and the aircraft nose drops below horizon line by 1[illegible] - 15°.

3. Loop is executed with a bank due to pilot's negligence of the artificial horizon.

This error changes loop recovery direction; it is easily corrected by deflecting the stick counter-banking at any stage of the loop.

Oblique Loop

Oblique loop is executed at the same altitudes and speed as the Nesterov's loop is.

Prior to entering the maneuver the pilot establishes a prescribed speed and sets a bank of 1[illegible] - 45°. The aircraft smoothly enters the upward path. The bank initially set is [illegible] maintained all along the path. Control stick handling procedure is similar to that of the loop. The aircraft flies a closed curve in the plane oblique to the horizon.

The main problem for the pilot is to maintain a prescribed bank when reaching and passing the top point. The difficulty consists in the fact that the aircraft reaches the top point in wheels-up position and pilot's notion of ground and horizon position acquires opposite meaning. For the purpose of correct determination of attitude of flight, the pilot must always remember that if the aircraft has entered oblique loop with a left bank, at the top point its port wing should be low and starboard wing high relatively to the horizon line. When the aircraft enters the downward path (diving), the pilot gives slightly the pedal to the side opposite to the bank to maintain the required direction during recovery. When the aircraft assumes level flight attitude, the pilot [illegible] the bank and smoothly sets the pedals neutral. In the [illegible] of the oblique loop is executed correctly, the [illegible]

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may deteriorate into steep spiral due to bank increase and aircraft rotation around its longitudinal axis.

If the pilot is uncertain of determining attitude of flight at the top point, he must eliminate the bank and do the second part of the loop proper.

For the sake of practicing the maneuver, the pilot is advised to establish a bank not exceeding 1 - 2° when doing the maneuver during his first flights and to increase bank to 40° in the process of further training.

Roll-off-the-top

Roll-off-the-top is executed at altitudes below 5 [illegible] m when the engine is operating at full thrust power setting and at altitudes not exceeding 7[illegible] m. in case afterburning power is used.

For training purposes roll-off-the-top is practiced at 4000 m. and at maneuver entering speed V_{IA} = 1[illegible] km/hr. The procedure of roll-off-the-top execution is similar to that of the first half of the loop. After the aircraft reaches top point in wheels-up position and its nose is aligned with the horizon (speed at this moment must not be less than 37[illegible] km/hr), the pilot turns the aircraft 18[illegible]° around its longitudinal axis during 3 - 4 sec. by smooth deflection of the control stick and slight pressure on the pedal into the turn.

If at the top point of the roll-off-the-top the speed is below 350 km/hr, 180° turn around longitudinal axis is not to be executed and the maneuver is to be converted into the loop. During the turn after the aircraft completes 90° turn, the pilot deflects the stick to the side of recovery and at the same time releases back stick pressure, to maintain the direction and decrease angle of attack with the aim to avoid loss of speed.

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10 - 15° prior to completing 180° turn the controls are neutralized. After the aircraft assumes level flight attitude and picks up a required speed, the pilot reduces engine r.p.m.

Roll-off-the-top with afterburner on is even easier to perform. In the process of its execution, speed drops more slowly and at the same rate of back stick pressure which is used during full thrust power loop and roll-off, the aircraft reaches the top point at 50[illegible] - 55[illegible] km/hr and gains 40[illegible] - 4[illegible]0 m. Afterburner is cut off when the aircraft recovers level flight attitude. Errors habitual in execution of roll-off-the-top are similar to those committed during execution of loop first half. In addition, the following errors may occur:

(a) premature 180° turn around longitudinal axis at the top point which leads to roll-off-the-top recovery at a speed lower than the prescribed one;

(b) retarded 180° turn around longitudinal axis at the top point which leads to altitude loss during recovery.

Roll

The aircraft is designed to execute snap and slow rolls at IAS not less than 4[illegible] km/hr. For training purposes rolls are executed at medium and high altitudes at IAS = 6[illegible] - 7[illegible]0 km/hr.

Prior to executing snap roll, the pilot [illegible] speed in level flight and establishes a pitch angle of [illegible] - 1[illegible]°. After fixing this position by smooth deflection of the control stick and by application of rudder to the [illegible] direction the pilot starts 360° turn around longitudinal axis.

Due to high efficiency of the ailerons the [illegible] was very fast (4 - 5 sec.), and because of this [illegible] executing this maneuver for the first time [illegible] maneuver recovery. The controls are not fully [illegible] - 35° prior to completing 360° turn.

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Snap roll execution procedure at high speeds does not differ from that at 6[illegible] - 7[illegible] km/hr speeds.

To execute slow level roll the pilot establishes a pitch angle of 10 - 15° before entering the maneuver, and by intelligently deflecting the control stick to a required direction turns the aircraft around its longitudinal axis. The turn is assisted by the pedal given into the turn. When the aircraft attains 45 - 5[illegible]° bank, back stick pressure is released to ward off aircraft turn and nose drop. The latter is also prevented by simultaneously giving the pedal to the side opposite the turn. The pedal is deflected as the aircraft is manifesting its tendency to drop the nose; at 9[illegible]° bank its value reaches maximum. With further turn the control stick is moved forward and pedal deflection diminishes.

After the aircraft completes 18[illegible]° turn, the pilot sets the pedals neutral and moves the control stick forward planning to keep the aircraft nose 10 - 15° above the horizon line. At the same time the control stick continues to move into the turn to maintain the rate of the turn. At 270° of the turn the pilot again begins to give the pedal in the direction of the turn to prevent aircraft nose dropping, planning for that at 270° of the turn the deflection attains its maximum value and then decreases again. 45 - 60° prior to completing 360° turn the pilot gently applies back stick pressure to forestall nose dropping.

On approaching level flight attitude, the controls are set neutral and the aircraft settles down to level flight.

Slow barrel roll is executed during 11 - 12 sec. In the process of roll execution aircraft angles of attack change their polarity. Part of the maneuver is performed at positive angles of attack, the other part - at negative ones and the pilot experiences variable-polarity G-loads.

In addition to rolls, the aircraft is able to perform double and multiple horizontal rolls which consist in continuous execution of two or more ordinary rolls. Entry speed of

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a double roll is 50 - 100 km/hr higher than that of a single roll.

Characteristic errors in execution of roll are as follows:

1. Change of altitude in the process of roll execution. This error occurs due to uncoordinated handling of the controls.

2. Non-uniform rate of turn and increase of turn radius due to incommensurate stick and pedal movements.

Zoom

Zoom is performed at all ranges of altitude at normal rated, full thrust and afterburning power settings. Altitude, gained during its execution, depends on entry speed and angle of climb.

Angle of climb depends upon flying altitude and may be enhanced to 80°. Zoom entry speed (or M-number) must not exceed maximum permissible values.

For training purposes zooms are performed at medium and high altitudes and in stratosphere at entry IAS = 950 - 100[illegible] km/hr. During practising zooms are executed with gradual increase of angle of climb: first at medium, then at high altitudes and later in stratosphere. To pick up speed faster, the aircraft is accelerated at shallow descent.

After prescribed speed has been obtained, the pilot establishes and fixes a required angle of climb by smoothly applying back pressure to the stick. Angle of climb and horizon-free attitude are checked on the artificial horizon indicator.

On reaching prescribed recovery speed, which depends on angle of climb, the aircraft is rolled into a turn by pilot's coordinated movement of the control stick and pedal. [illegible] as the aircraft nose reaches the horizon line, the aircraft resumes level flight attitude. Zoom recovery [illegible] not less than 450 - 500 km/hr at angles of climb [illegible] not less than 400 - 450 km/hr at angles of climb below [illegible]

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Establishment of bank and decrease of angle of climb during zoom recovery are planned so as to avoid negative and zero G-loads and to return to level flight at [illegible] not less than 35[illegible] - 36[illegible] km/hr.

If necessary zoom recovery can be accomplished without a turn.

In this case after attaining maneuver recovery speed, the pilot turns the aircraft wheels up (by 18 °) by correspondingly handling the control stick and slightly pressing the pedal, and at the same time decreases angle of climb.

As the aircraft nose lowers to the horizon line and speed drop the pilot makes 18 ° turn around longitudinal axis by using coordinated control and returns the aircraft to level flight. Turns around longitudinal axis must be performed in a manner to exclude occurrence of negative G-loads.

Characteristic errors in execution of zoom are as follows:

(a) zoom recovery speed is lower than the prescribed one. This error occurs if recovery is delayed or sluggish;

(b) failure to maintain angle of climb. This error is due to the fact that after the aircraft assumes climbing attitude the angle of climb is not fixed by slight release of back stick pressure;

(c) zoom recovery with negative G; this error is due to incommensurate fore movement of the stick during recovery;

(d) early elimination of bank during recovery, particularly at high angle of climb; this may lead to speed drop below the prescribed one and to creation of negative G.

Zooming Half-Roll

Zooming half-roll is performed at all altitudes from 4000 to 12,000 m. and at the same entry speed as that as used during execution of zoom.

For training purposes zooming half-roll is executed at entry altitudes of 5000 - 10,000 m. at normal [illegible] thrust and afterburning power settings.

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Prior to entering the maneuver, the pilot accelerates the aircraft to the prescribed speed, then by smoothly applying back pressure to the stick, enters the aircraft into climb at an angle, the value of which depends on pilot's flying efficiency. Pilots practising this maneuver for the first time must not exceed angles of climb of 45 - 50°. Angles of climb are increased to 60 - 80° as a trainee advances in execution of this maneuver.

After reaching IAS = 500 - 450 km/hr (if angle of climb is 45 - 50°) or 6[illegible] - 550 km/hr (if angle of climb is 60 - 80°), the pilot makes 180° turn around longitudinal axis by smooth coordinated handling of the controls and, watching the speed, applies back pressure to the stick. As soon as the aircraft nose aligns with the horizon line, he gently reduces engine r.p.m. At this moment IAS must not be lower than 350 km/hr. Then the pilot performs the second half of the loop.

Errors usually committed during execution of this maneuver are similar to those encountered during execution of [illegible] half and loop second part.

Spiral

[illegible] spiral executed with 45° bank at IAS = 50[illegible] - 55[illegible] km/hr and with the engine control lever being in idle speed position renders the best results.

Prior to entering spiral the pilot sets a [illegible] and then by coordinated movements of the pedals and control stick maneuvers the aircraft into a turn. [illegible] checked on artificial horizon indicator as well as on [illegible] of other flight and navigation instruments (speed indicator, rate of climb indicator, altimeter, turn and bank indicator, etc.).

If spiral is properly executed at constant [illegible] artificial horizon and turn-and-bank indicator [illegible] and the ball must be in the center. [illegible]

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by corresponding variation of angle of bank of aircraft longitudinal axis relatively to the horizon (near high or [illegible] attitude). Procedure of spiral execution is basically [illegible] to that of turn execution. If the maneuver is entered at 500[illegible] m., loss of speed during one turn of spiral will be 1500 - 1600 m.

Spiral recovery is accomplished by coordinated [illegible] of the control stick and pedals and simultaneous increase of engine r.p.m. required for maintaining the initial speed level flight. Engine r.p.m. may be also increased in glide after spiral recovery.

During steep spiral recovery when aircraft longitudinal axis-to-horizon angle of bank exceeds 3[illegible]°, the pilot [illegible] the bank first and then performs dive recovery.

With landing gears and flaps down, spiral is executed [illegible] increased r.p.m. and at IAS $V_{I[illegible]}$ = 45[illegible] km/hr with rate of descent not exceeding 25 - 3[illegible] m/sec.

Characteristic error in execution of spiral is bank increase accompanied by aircraft nose drop and speed [illegible] which forces the aircraft into steep spiral. This error is corrected by elimination of the bank followed by decrease of angle of descent.

Diving

For training purposes, diving is practiced at high altitudes and in stratosphere. Diving is entered at the same speeds as half-roll. Speed and M-number during dive and the recovery must not exceed maximum permissible values. Dive is to initiated from a descending turn, half-roll or from a level flight both with or without application of air brakes.

The aircraft is designed to execute diving at various angles, including vertical diving. The latter is initiated at altitudes above 13,000 m., and the recovery from the vertical dive should be started at an altitude not lower than 9[illegible]

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prior to initiating dive from a turn the pilot selects a recovery check point, sets a required speed and by smooth coordinated handling of the controls enters a turn. In the second half of the turn, depending upon the value of a given angle of dive, he lowers the aircraft nose and reduces engine r.p.m. After the aircraft turns to head to the selected check point, he eliminates the bank, and establishes a given angle of dive by reference to the artificial horizon readings.

After losing a required altitude or reaching a required speed, the pilot returns the aircraft to level flight by smooth back stick pressure. Prior to dive recovery, he consults the artificial horizon to check if the aircraft is bank-clean. During dive recovery and return to level flight and depending upon actual speed, engine r.p.m. will be smoothly increased.

Dive initiation from a half-roll is similar to execution of half-roll first part. After the aircraft enters downward path the pilot establishes a given angle of dive. Dive entry from a half-roll is mainly used when vertical diving is practised. Vertical diving angle is determined by aircraft position in relation to the ground. Recovery direction is checked by the compass.

To initiate dive from straight flight the pilot sets a required speed and selects a check point in accordance with angle of dive. Then, by smooth and coordinated handling of the controls, he turns the aircraft wheels up (by 180°) and at the same time lowers its nose down. As the aircraft nose approaches the selected check point, the pilot by reverse movements of the controls turns the aircraft around its longitudinal axis again and dives in the direction of the selected check point. Bank-clean attitude and given angle of dive are determined by aircraft position relatively to the ground surface and by the artificial horizon.

Characteristic errors in execution of dive are as follows:

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1. Failure to maintain a given angle of dive. To correct this error the pilot establishes a given angle by some handling of the control stick and checks it on the artificial horizon indicator (angles are allowed up to 60°).

2. Diving is performed with a bank. The error is corrected by deflecting the control stick to the side opposite the bank. Bank elimination is checked by the artificial horizon.

Spin

The MiG-21 -ib aircraft spins only in case of gross flagrant error in flying or when the spin is provoked.

Aircraft Behaviour at Speeds Close to Flight Stall and Early Spin Stage

When the engine is operating within the range of IAS speed and normal rated power settings and the landing gear and flaps are retracted, reduction of flying speed, by adding back stick pressure, to IAS = 280 km/hr (and below) entails shaking vibration, intensity of which grows in sufficiently with further speed drop. At V_{IAS} = 280 km/hr and below efficiency of the ailerons diminishes considerably, and when speed drops below 250 - 240 km/hr, the ailerons become ineffective.

Efficiency of the stabilizer and rudder remains sufficient to maintain level flight without a bank (as well as enter gliding) up to V_{IAS} = 220 km/hr. Balancing position of the stick at minimum speed corresponds to two thirds of its aft travel distance.

At IAS = 215 km/hr the aircraft loses its stability and starts to roll, dropping its nose at the same time, though the rudder and ailerons are neutral. If at this moment the stick is moved forward, the aircraft will assume a lower dive

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of attack and become controllable; if a pedal is applied, the aircraft will break into spin in the direction of forward pedal.

Aircraft Behaviour in Spin

Characteristics of left-hand and right-hand spins practically do not differ (except that right-hand spin has more pronounced nonuniformity of turn). During the first one and a half turn the aircraft moves quite stably without stops, slowing down the rate of turn at the end of the turn and raising its nose 20 - 30° above the horizon. Then, nonuniformity of turn increases, after 1/4 - 1/2 turn the aircraft stops turning, rocks its wings and then continues to spin into the same side. Aircraft longitudinal axis-to-horizon angle of bank varies from 80° in diving to 20 - 30° in pitching. These variations of aircraft nose vertical attitude during spin as well as constancy of turn direction are a feature of this aircraft and distinguish it from aircraft of other types. Loads imposed on the pedals during spin are variable. The aircraft experiences heavy vibration during aircraft turning and particularly during interruption of turn.

Spin Recovery

If the pilot was not able to keep the aircraft from spinning and the latter breaks into spin, he must set idle speed power, give the pedal into the spin and apply back pressure to the stick (ailerons being neutral). After waiting for one turn to complete, he recovers from the spin in the following order:

(a) applies full rudder in the opposite direction by a brisk forward movement of the pedal;

(b) in 0.5 - 1 sec. moves the stick forward and behind neutral position;

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(c) after the aircraft stops turning, sets the pedals neutral and as IAS builds up (up to 370 - 400 km/hr), [illegible] recovers the aircraft from dive.

During deflection of the pedal and force movement of the stick the ailerons must be kept strictly neutral.

When the pedal is deflected, the aircraft starts to slip down the turn, and after the stick is moved forward, it recovers from the spin with about one turn delay.

To recover from spin during turn interruption, it is sufficient to set the pedals neutral and to move the stick forward. In this case the aircraft recovers from spin with[illegible] delay.

If during spin recovery the stick is sent full forward, the aircraft may assume negative angles of dive.

Altitude loss during spin recovery, from the moment the the controls are set for recovery to the moment when the aircraft returns to level flight, is 30[illegible] m. Altitude loss in spin turn is 500 - 600 m.

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Chapter IV

STRATOSPHERIC AND CEILING FLYING

KKO-3 Oxygen Equipment Set

The KKO-3 oxygen equipment set is designed for oxygen supply of the pilot during flights at altitudes up to 25,000 m., providing him with oxygen in the following conditions:

(a) long-time supply:

when flight is performed at altitudes up to 25,000 m. and the cockpit is sealed or at altitudes up to 12,000 m. when the cockpit is not sealed;

(b) momentary supply:

(1) up to 10 min. in case of depressurization of the cockpit at altitudes from 12,000 to 25,000 m. when the set is used as pilot's oxygen emergency supply while the aircraft is descending to safe altitude;

(2) during pilot's ejection at altitudes up to 25,000 m. with simultaneous automatic transition to the KM-27 parachute oxygen apparatus supply.

At altitudes up to 11,000 - 13,000 m. oxygen is supplied to the pilot via the KM-4 oxygen regulator economizer only at the moment of inhaling. And to provide for required value of oxygen partial pressure in the breathing mixture, oxygen percentage in the mixture enhances as flight altitude increases from 0 to 10,000 m.; beginning from 10,000 m. the system supplies pure oxygen for pilot's breathing.

For the purpose of forestalling oxygen lack at altitudes between 6000 and 12,000 m., slight excessive pressure is maintained in the breathing system to prevent dilution of oxygen by

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atmospheric air if the pressurized helmet (o[illegible]) is not airtight.

In case of cockpit depressurization at altitudes above 11,000 - 13,[illegible] m. oxygen is supplied to the pilot via the KM-34 oxygen regulator under excessive pressure in a continuous flow at a rate of 1[illegible] - 2[illegible] lit/min.

With altitude increase oxygen excessive pressure in the breathing system grows correspondingly to allow maintenance of oxygen partial pressure at all altitudes at a level maintained during pilot's inhalation of pure oxygen not subjected to excessive pressure at 12,[illegible] m.

For the purpose of preventing respiration and blood circulation disorders when oxygen under excessive pressure is used for breathing, pressure is also built up in the inflatable rubber bladders of the partial pressure suit to create counterpressure on pilot's body surface. Pressure in the suit pneumatic system is automatically adjusted according to variations of pressure under the pressurized helmet.

In case of rapid change of atmospheric pressure, the oxygen regulator automatic arrangement prevents occurrence of non-compensated pressure in the breathing system and provides for suit inflatable rubber bladders pressure build up during 2.5 - 3 sec.

During ejection, separation of the parachute oxygen apparatus from the oxygen regulator and switchover to parachute oxygen apparatus supply are performed automatically.

When flight is executed at altitudes up to the aircraft ceiling and the cockpit is pressurized (air-dilution system CM) design rate of oxygen consumption will be 6 lit/min., while that of oxygen consumption when flight is carried out at altitudes above 11,000 m. with the cockpit being depressurized will be 20 lit/min.

Excessive pressure respiration requires special habits which are acquired in the process of ground practising. Pilots are trained in excessive pressure respiration and talk with

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the help of training oxygen set [illegible] in the course of initial adjustment of the BKK-3M high-altitude pressure suit and pressure helmet (mask). Afterwards the acquired habits are kept up by means of regular training in the cockpit for 5 min. prior to each stratospheric flight.

Those pilots, who have successfully completed training and necessary practising in excessive pressure respiration and talk, may be allowed to perform flights at altitudes above 12,000 m. using the KKO-3 oxygen equipment set.

The KKO-3 oxygen equipment set is displayed in Fig.35.

The [illegible] pressurized helmet consists of a washable cloth helmet, transparent face-piece, base with inner rubber and cloth bladders and helmet proper.

The transparent face-piece of the pressurized helmet is provided with electrical heating to de-fog it when temperature is above zero or to de-ice it if temperature drops below zero.

The high-altitude pressure suit is conceived to exert pressure on pilot's body surface with the aim to compensate oxygen excessive pressure in the lungs as well as to safeguard the pilot against G-loads experienced in flight. The suit consists of a light overall with zippers, straining device (inflatable band and bladders with rubber tubes for oxygen supply), and anti-G device incorporating leg and abdominal bladders, which are supplied with air via a filter and the [illegible] pressure automatic regulator, the latter is used with the BKK-3M suit at MINIMUM ([illegible]) duty of operation.

The BKK-3M suit and the [illegible] pressurized helmet constitute pilot's personal equipment and are selected according to his size and build. The other equipment is installed in the aircraft.

The [illegible]-27 parachute oxygen apparatus is designed to supply the pilot with oxygen during ejection at altitudes up to 25,000 m. as well as to serve as oxygen emergency supply providing for pilot's respiration during airborne descent to safe altitude in case of the main oxygen supply system failure.

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The KM-27 apparatus is charged with oxygen under pressure of 15[illegible] - 13[illegible] kg/sq.cm. which is checked by its pressure gauge watched through a peep-hole.

A fully charged apparatus is packed into a [illegible] pocket and is connected to the main breathing system of the aircraft. During ejection, switch-over to the KM-27 parachute oxygen apparatus supply is performed automatically.

Main version of pilot's high-altitude equipment includes:

(a) the BKK-3M high-altitude pressure suit;

(b) the [illegible]-4M pressurized helmet;

(c) the POR-5 mask pressure ratio regulator;

(d) counter-pressure gloves and socks.

Pilots are supposed to have the KM-27 parachute oxygen apparatus on board and to use oxygen equipment during all types of flights.

Pilots are allowed to wear only the KM-3M oxygen mask without the BKK-3M high-altitude pressure suit and the [illegible] pressurized helmet up to 7[illegible] m. and at a speed not exceeding 750 km/hr, though the anti-G suit is mandatory. In this case the cylinder-to-suit oxygen supply hose must be plugged on the POR-5 mask pressure ratio regulator.

The KM-3M mask is used in flights up to 15,[illegible] m. and at a speed not exceeding 75[illegible] km/hr; the high-altitude pressure suit in this case being mandatory.

Pilots are not allowed to fly without the high-altitude pressure suit and pressurized helmet at altitudes above 15,0[illegible] m. and at speeds exceeding 75[illegible] km/hr as well as during execution of a combat mission.

Counter-pressure gloves and socks are used in flights performed at altitudes above 20,000 m.

Mandatory usage of the BKK high-altitude pressure suit and the [illegible] pressurized helmet at speeds exceeding 75[illegible] km/hr at all altitudes is necessitated by the fact, that in case of cockpit depressurization at these speeds cockpit "altitudes" reach considerable values due to potential air bleed.

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Pre-Flight Preparation of KM-3 Oxygen Equipment Set

Prior to putting on the already adjusted bKK-3M high-altitude pressure suit the pilot checks if the cloth, seams, covers and lacing of the straining device are intact, the zippers are not jamming and the bladders of the straining and anti-G devices are airtight. He inspects the pressurized helmet, making sure that the inner rubber bladder has no ruptures, the microphone is secured safely, the fastening lock is operative, the transparent face-piece as well as inlet and outlet valves are clean and intact.

In addition the pilot checks if the outlet valve diaphragm is intact; for this purpose he exhales into the hose attached to the outlet valve. Then, he checks the inlet valve for airtightness by inhaling through the crimped hose; the inlet valve is considered airtight if air does not inhale through the hose.

If the KM-3M oxygen mask is to be used in flight, the pilot will check if the hoses, inlet and outlet valves, rubber washer in the bayonet lock of the hose attached to the outlet valve are intact. The mask inlet and outlet valves and mask-to-face tightness compensator bladder are also checked for airtightness. To check the mask outlet valve for airtightness, the pilot connects the outlet valve hose bayonet lock to the hose pipe connection, designed for connecting the tightness compensator to the hose; prior to this, he uncovers one of the inlet valves by inserting a match or a piece of folded paper under it. Then he tries to draw a deep breath. If the latter cannot be produced, the mask outlet valve is considered airtight. After the check the match or piece of paper must be removed from under the inlet valve.

To check airtightness of the tightness compensator bladder, the pilot inflates the bladder by mouth, crimps the compensator hose with the fingers and by pressing the bladder with hands, checks it for air bleeding.

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Prior to entering the cockpit the pilot checks the [illegible] of the [illegible]-27 parachute oxygen apparatus which must be [illegible] in the parachute bag pocket with its selector switch [illegible] so that on-off control mechanism is at the left side; the [illegible] control mechanism pin must be locked with a thread.

After making sure that the high-altitude equipment is operative, the pilot puts on the high-altitude pressure suit first and then fixes the pressurized helmet. The suit is to be worn above special knitted underwear (silk one in summer and woolen one in winter).

While putting the pressurized helmet on the pilot does the following sequence:

(a) puts on the cloth helmet, tucking the microphone-telephone leads connector under the helmet;

(b) passing his hands with palms turned inside, thrust the neck flap-obturator of the rubber inner helmet, on the latter end puts it on beginning from the back of the head;

(c) assisted by others, he smoothes the inner rubber helmet on the head and the sealing flap-obturator on the neck and checks if the rubber inner helmet was not ruptured in the process of putting on;

(d) plugs the microphone-telephone connector inside the helmet and arranges it under the chin so that it does not hinder head turning;

(e) zips the cloth helmet, tucks its cape under the suit and, if necessary, adjusts the cloth helmet to the head and neck by means of the lacing;

(f) puts the helmet on, and fixes it on the frame pins by means of lateral latches;

(g) fixes the microphone at a distance of 1 - 1.5 cm from the mouth;

(h) connects the transparent face-piece to the face frame and checks the helmet for airtightness; for this purpose, he closes the crimped hose outlet and tries to [illegible]

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deeply; the pressurized helmet is considered airtight if a breath cannot be produced.

After putting on the suit and the pressurized helmet, the pilot checks the suit close fitting and airtightness of the suit straining device bladders by gradually building up oxygen excessive pressure (by using the [illegible] or KW-5 sets) in them up to 1 kg/sq.cm. Excessive tightness or looseness is eliminated by means of adjusting lacing.

KK-3 Oxygen Equipment Set Pre-Flight

Check in Cockpit

On entering the cockpit the pilot snaps the pressurized helmet fastening hooks to a special yoke which is then fixed to the parachute harness lock (if the pilot wears summer clothing, the hooks will be fixed to the high-altitude pressure suit rings). Then he connects the hoses of the straining and anti-G devices and pressurized helmet to the [illegible]-2 common connecter and the [illegible]-3 regulator, plugs the helmet connection, fastens the safety belts, and arranges the [illegible]-3 pressure ratio regulator on the fastening lock which is installed on the parachute strap of the left leg lower fastening loop at the parachute harness lock. The [illegible]-2 common connecter upper block is to be fastened as follows (Fig.39).

A. Link Fastening

1. Pass the link through the leg fastening loop, without crossing the hoses, and snap the hook.

2. Tighten the link properly and tuck its loose end behind the parachute strap.

B. [illegible]

3. Pass the damper through the [illegible] fastening [illegible]

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4. Fix the damper hook to the lug on the [illegible] connector upper block.

After the above said procedure, the pilot, assisted by an aircraft equipment technician, checks operation of the oxygen equipment set in the following order.

Check under excessive pressure. With the oxygen supply valve already opened, the pilot turns on oxygen continuous flow by moving the oxygen supply handle installed on the remote control system panel from the [illegible] (H) to [illegible] (CH.NOL.) position, then closes with fingers the outlet of the [illegible]-3 regulator body.

By smoothly rotating the handwheel of the excessive pressure manual regulator, installed on the [illegible]-2 panel, counter-clockwise, the pilot builds up excessive pressure in the pressurized helmet up to 2[illegible] mm of water column indicated by M-2[illegible] pressure gauge (1[illegible] mm of water column if the [illegible] mask and high-altitude pressure suit are expected to be used in flight).

If with pressurized helmet excessive pressure in the suit tightness grows, and M-2[illegible] pressure gauge readings during inhalation and exhalation differ by 1[illegible] - 1[illegible] mm of water column (at 15 - 2[illegible]°C), the set is considered to be operating normally. In completing the check the pilot turns the excessive pressure manual regulator handwheel clockwise home and sets the cylinder-to-suit oxygen supply handle [illegible].

The set is considered to be malfunctioning if with the handwheel fully turned counter-clockwise, the pilot is [illegible] to build up excessive pressure in the pressurized helmet [illegible] to 2[illegible] mm of water column and in the mask up to 1[illegible] mm of water column.

Due to potential traumatic effects on the lungs it is not allowed to check the system under excessive pressure if the pilot is to wear in flight only the [illegible] mask without the high-altitude pressure suit.

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Check without excessive pressure. With the cylinder-suit oxygen supply handle not neutral and excessive pressure manual regulator handwheel turned full clockwise, the pilot inhales and exhales several times with the air-dilution switch installed on the KJ-2 panel turned successively to positions MIXTURE (OMSCH) and PURE OXYGEN (100% O_2). The KKO-3 oxygen equipment set is operating normally if the KK-16 indicator blinker opens and shuts. After the check, the air dilution switch must be turned to position MIXTURE (OMSCH).

Prior to flight the pilot must also check if the selector switches on the VK-2M amplifier are set in positions M and M, when the pressurized helmet is worn, and in positions M and A, when the oxygen mask is used in flight. The pressurized helmet microphone may become inoperative if the above mentioned procedure is not observed.

The pressurized helmet transparent face-piece heating rheostat is adjusted to the cockpit temperature by means of the rheostat handle.

KKO-3 Set Operation in Flight

The pilot should watch the set operation in flight by periodically checking oxygen quantity on the pressure gauge indicating oxygen pressure in the system.

It is equally indispensable to watch cockpit "altitude" on the VSKI-20 cockpit altitude and pressure differential gauge. If the cockpit "altitude" does not exceed 12,000 m, the set may be used during a period determined by oxygen available on board.

In case the cockpit "altitude" has increased and is within 12,000 - 25,000 m. limits (the cockpit becomes depressurized), the set may be used only for a short period of time (from 5 to 10 min.). The pilot in this case must check excessive pressure by KI-200, pressure gauge indications.

It must be remembered that at abrupt increase of the cockpit "altitude" (when the cockpit is depressurized quickly

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1 - 2 sec.) at altitudes above 1[illegible], [illegible] m., the pilot will experience strong initial pressure on his body in the region of the waist, chest and abdomen. It is a normal phenomenon which menaces neither pilot's health nor his life.

During prolonged flights at 11, [illegible] - 12, [illegible] m. with the cockpit being depressurized, the cylinder-to-suit oxygen supply switch installed on the [illegible]-2 panel must be set in position AUTO OFF ([illegible]) as the device turns off automatically at 8[illegible] - 9[illegible] m., and at these altitudes oxygen supplied by the oxygen concentrator is quite sufficient for pilots breathing.

It must be borne in mind that after oxygen supply has been cut off it cannot turn on automatically again, therefore, if the pilot plans to climb to an altitude above 1[illegible], [illegible] m. he must turn the oxygen supply switch to position [illegible] (B.

If the pilot experiences oxygen lack while breathing through the individual oxygen regulator, he must switch over to pure oxygen breathing; for this purpose, the air diluting switch on the [illegible]-2 panel is turned to position PURE OXYGEN (100% O_2). If after this the pilot still experiences oxygen lack, he must turn on cylinder-to-suit oxygen continuous flow by setting the [illegible]-2 panel oxygen supply switch in position SUIT ON ([illegible]). After this the suit stabilizing device bladders are inflated with oxygen and the latter is delivered to the pressurized helmet or mask in continuous flow.

It must be remembered that in this case oxygen consumption increases by 3 - 4 times.

If the pilot experiences acute pain in his ears due to rapid change of pressure in the pressurized helmet during aircraft descent, he should also turn oxygen continuous flow on by setting the [illegible]-2 oxygen supply switch in position [illegible] ON ([illegible]). The continuous flow will be turned off after the aircraft assumes level flight attitude.

The pilot must not overlook operation of the [illegible] face-piece electrical heating in flight. If the electrical

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heating is functioning properly, the face-piece will not fog, visibility will be quite satisfactory and the face will not be overheated.

Physiological Features of Stratospheric Flight

Physiological features of stratospheric flight are primarily conditioned by high degree of air tenuity, low temperature (-56°), high intensity of the ultra-violet spectrum of solar radiation and insignificant humidity.

The most serious influence upon pilot's organism is exerted by atmospheric pressure drop with altitude increase due to which oxygen partial pressure in the lungs also reduces.

It is an established fact that pure oxygen respiration at atmospheric pressure ensures vital activity of the organism only up to 12, [illegible] m. Due to oxygen lack a human loses consciousness in 2 min. at 13,5[illegible] m. and in 9 sec. at 16,[illegible] m. Prolonged stay in stratosphere at low barometric pressure may cause decompression disorders manifested in skin itching, joint and muscular pain, pain in the chest and abdominal cavity, cough, vision disorder, cutis and temporary paralysis. Organism cooling, oxygen lack, muscular work to a certain extent promote decompression disorders. Prolonged breathing with pure oxygen prevents their development.

The MiG-21F-13 aircraft pressurized cockpit and the oxygen equipment set (KKO-3) provide for safe flying at altitudes up to the service ceiling of the aircraft.

The [illegible] pressurized helmet ensures good field of vision outside the cockpit, though it hampers surveillance of the instruments and controls located on the lower and upper side parts of the panels and subpanels at cockpit port and starboard particularly when excessive pressure is delivered to the pressurized helmet and straining device the [illegible] when the [illegible] suit is used.

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Pilot's high-altitude equipment requires proper care and drying after each flight. Particular attention should be paid to proper and careful handling and storing of the detachable transparent face-piece.

Value of excessive pressure in the pressurized helmet depends on barometric pressure in the cockpit. Excessive pressure is created at the moment when barometric pressure in the cockpit corresponds to an altitude exceeding 12,[illegible] m. It grows with altitude increase and at temnity corresponding to 18,[illegible] - 2[illegible],[illegible] m. it will reach 17[illegible] - 19[illegible] mm of water column.

If the cockpit is depressurized in flight, the air begins to bleed from it and due to this barometric pressure in the cockpit drops sharply. There was an incident, when the cockpit of the aircraft, which was flying at 8[illegible] m. and at supersonic speed, was depressurized and the "altitude" in it rose above 12,[illegible] m.; at that moment the aneroid-starter went into action and the KKO set started to deliver oxygen under excessive pressure.

These pilots will be allowed to perform flights at altitudes above 12,[illegible] m. with usage of the KK[illegible]-3 set, who have undergone training and practising in respiration and talk at excessive pressure up to 2[illegible] mm of water column and acquired habits in handling the controls and cockpit equipment both with and without excessive pressure in the pressurized helmet and suit straining device bladders.

Flight personnel training and practising in excessive pressure respiration and talk are conducted in accordance with the Methodical Instructions on Usage of Oxygen Breathing Equipment for Respiration at Increased Pressure.

Pilot's ability to handle the controls and cockpit equipment is checked in the cockpit, the pilot being fully equipped for high-altitude flying.

With the straining device bladders and pressurized helmet void of excessive pressure the pilot checks his ability to

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handle all the controls and equipment of the cockpit, then after building up excessive pressure he checks his altitude to handle those controls which are indispensable for emergency procedures during cockpit depressurization at altitudes above 12,000 m. and aircraft descent to safe altitude.

Only after that the pilot acquires confidence and certain habits in controlling the aircraft in any circumstances.

Stratospheric flights prefer additional requirements to pilot's vision. With altitude increase, intensity of solar radiation enhances and at the same time the amount of diffused light diminishes due to which sharp contrasts will be noticed between objects lit by the sun and those being in the shade.

Laboratorial research work, conducted in conditions of prolonged observation of glares, which may be encountered at high altitudes, made it possible to establish the fact that the pilot requires so much time to take instrument readings and distinguish other objects, located in shaded parts of the cockpit, that it becomes a problem to carry out instrument flight. Therefore, while flying in stratosphere the pilot should avoid long stare at bright objects lit by direct sun rays.

Glare effect on pilot's eyes experienced during prolonged flight into the sun and long observation of clouds, lit by the sun, and of polished parts of the aircraft may cause eye disease manifested in acute conjunctivitis accompanied by photophobia and epiphora. The disease progresses 5 - 6 hours after the glare effect; but under favourable conditions the disease will be cured in 2 - 3 days.

Visual search of air targets in stratosphere presents a problem even though flight path of a target is known. In these conditions an aircraft target appears suddenly and at closer distances.

It is primarily due to the fact that the pilot is unable to judge properly the depth of space against the background of cloudless blue sky.

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The pilot experiences difficulty not only in target search but also in judgement of distance to the target if he has not had special training. If at medium altitudes visual range of detection of a single target is 5 - 6 km., at high altitudes this distance reduces considerably. At foreshortening of observation being equal to 1/4 and 1/4 and at vertical attitude of the target relative to the sun, the range of a single target detection increases with altitude growth up to 9[illegible] m., and at 9[illegible] m. it is 7 - 8 km., but further ascent leads to reduction of the range and at altitudes of 1[illegible] - 1[illegible] it will be [illegible] and 4 km., respectively.

During flights at altitudes exceeding 12,[illegible] m. the horizon is poorly visible due to considerable distance and hence its line of observation becomes indistinct and looks dim. This factor presents difficulty in determining attitude of the aircraft.

Ground check points are poorly visible from altitudes of 14,[illegible] - 15,[illegible] m. The pilot is able to distinguish only big rivers and reservoirs by light reflection in sunny weather and cities and large populated areas - by smoke. Thus, [illegible] difficulties in aircraft flying in stratosphere under any meteorological conditions are to a certain extent similar to those experienced in bad weather flying.

During preparation for stratospheric flights pilot's pre-flight diet and rest acquire vital importance. In any flight and particularly in a flight as complicated as a stratospheric one, pilot's digestion deterioration, deterioration of gastric juice secreting and motive functions of the stomach and bowels is also inevitable. The above mentioned circumstances are conducive to food delay in the stomach and to extensive gas evolution. Atmospheric pressure drop with altitude increase causes expansion of gas in the alimentary canal.

If these cases are not releived in time, the expanded stomach and bowels will displace other internal organs, which leads to deterioration of respiration and blood circulation conditions.

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Considerable expansion of the stomach and bowels due to gases may cause acute pain resembling that experienced during partial unpassability of the bowels, acute appendicitis and volvulus.

If with altitude increase the gases are forcibly detained in the stomach, then after a certain degree of bowels expansion their spontaneous relief becomes impossible.

Therefore, pilot's high altitude nourishment must consist of a special diet. The latter should include easily assimilated but sufficiently caloric food and exclude excessive quantity of fat and cellular tissue. The food rich in fat is poorly digested while the food containing much cellular tissue (beans, peeled barley, oatmeal, horse radish, etc.) increases gas evolution. Aerated drinks are not to be taken.

The diet must contain maximum high percentage of the B, E, A vitamins.

Good pre-flight rest and particularly sufficient sleep play an important role in successful execution of stratospheric flights.

Pilots must have not less than 8 hrs of night sleep in good conditions.

Aircraft Ceiling and Procedure of Climbing

The aircraft ceiling implies maximum altitude at which the aircraft can perform steady level flight. At this altitude the aircraft is able to execute level flight at only one, quite certain speed which will be both its maximum and its minimum flying speed.

Subsonic and transonic aircraft climb their ceilings at maximum surplus thrust power setting and therefore climbing is performed at maximum rate of climb. The only altitude, that is aircraft ceiling, corresponds to this only condition of maximum climbing rate.

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operation of supersonic aircraft, and the [illegible] fighter is one of them, near the ceiling and at the ceiling is characterized by certain features which distinguish it from operation of subsonic and transonic aircraft.

These features pertain to somewhat different change of surplus thrust relatively to flying speed (Fig.4).

As is shown in the figure, the supersonic aircraft has two conditions of maximum rate of speed (the maximum of the surplus); transonic one (at a speed close to sonic) and supersonic one (at a speed exceeding sonic speed).

The first condition proceeds from the fact that aircraft drag has its minimum at the best flying speed which is close to sonic speed. The second condition lies in supersonic speed and proceeds from the features of engine thrust change according to flying speed: at supersonic speeds the thrust at first grows intensively (considerably faster than drag), and then reduces sharply. The result is the second maximum of thrust surplus.

In conformity with this, the supersonic aircraft has two static ceilings: transonic one and supersonic one.

The ceiling is called static because it is reached by an aircraft flying at constant speed along a trajectory, i.e. without transformation of aircraft kinetic energy (flying speed) into potential one (altitude).

From rate of climb and particularly fuel consumption point of view the best climb for the MiG-21 -13 aircraft will be at transonic speed at low, medium and high altitudes and at supersonic speed in stratosphere. Conditions and versions of climb are given in Chapter II.

For practical flying it is highly important to know maximum flight altitude at which the aircraft can execute engagement, coordinated turn to the target and attack without losing altitude.

In this connection it is necessary to mention aircraft combat ceiling which is defined as maximum altitude of air-

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effective combat operation at which the aircraft can execute a steady turn in horizontal plane with 30° bank.

Depending on flying speed, the combat ceiling of the MiG-21-13 aircraft is 800 - 1[illegible] m. lower than the static one.

In the process of combat training it may often happen that during ceiling flying the maximum altitude reached in flight considerably differs from the aircraft ceiling indicated in its flight characteristics; and in summer time it will usually be lower and in winter - higher. It is explained by the fact that actual atmospheric conditions of flight (temperature, in particular) near the ceiling differ from standard atmospheric conditions for which the aircraft ceiling, indicated in aircraft flight characteristics, has been rated.

Rate of climb and consequently aircraft ceiling, reached in flight, decrease with air temperature growth in stratosphere and increase when the temperature drops.

Due to stratospheric air temperature deviation from the standard temperature, the MiG-21-13 aircraft ceiling ΔH changes according to the equation

$$\Delta H = -50 \cdot \Delta t.$$

It means that temperature deviation by 1° changes the ceiling by 50 m.

Procedure of Aircraft Flying in Stratosphere and Close to Ceiling

Stratospheric flights and, all the more, ceiling flights require intensive training of flight personnel at altitudes and high altitudes and at all speeds.

The most characteristic features of stratospheric and ceiling flights are as follows:

(a) diminution of range of speeds and operational angles of attack of the aircraft with altitude increase;

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(b) deterioration of aircraft manoeuvrability at the expense of net G-load reduction;

(c) deterioration of visual and space orientation conditions due to high angles of pitch in flight;

(d) slight deterioration of aircraft stability and controllability which complicates launching of attack as the aircraft roll increases.

In addition, while flying the [illegible]-21-15 aircraft at altitudes close to the ceiling the pilot encounters a number of features which must be taken into account. These are as follows:

(a) cone travel to the extreme position (when the aircraft is accelerated to M-number exceeding 1.9) is indicated neither by light nor by mechanical signals and due to this the pilot experiences uncertainty in reliability of engine operation; change of engine sound is the only opportunity to check engine operation and it requires great attention of the pilot;

(b) flying speed cannot be reduced as the engine thrust with afterburner on cannot be regulated and air brake efficiency is low;

(c) pedals experience great forces as the whole flight is carried out at supersonic speeds;

(d) control stick forces must be relieved by fairly [illegible] application of the "trimming effect" mechanism as the deflections of the controls are great and momentary pressure on the "trimming effect" button is insufficiently (it seems that the "trimming effect" mechanism is not effective enough); if the "trimming effect" mechanism control button, however, is kept sunk for a sufficiently long time, the stick forces will be relieved completely;

(e) pressurized helmet does not allow the pilot to [illegible] the terrain, as it hampers the pilot to look overboard;

(f) after the cone reaches the extreme position at M = 1.9, the flying speed builds up rapidly and the aircraft is fast to pass M-number limit (2.05), therefore, the pilot

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must watch M-number increase closely and timely cut off afterburner.

At 20,000 m. atmospheric pressure decreases 18.5 times and air density - 14 times. Engine thrust reduction with altitude increase leads to continuous decrease of rate of climb. Thus, for example, if the MiG-21-13 aircraft is flying at afterburning power setting, without a drop tank, its rate of climb at 15,000 m. will be 95 m/sec., at 18,000 m. - 41 m/sec. and at 19,500 m. only 7 - 8 m/sec.

In stratosphere with altitude increase the maximum speed of level flight, limited by M = 2.5, remains constant and is equal to 2130 km/hr, but the minimum speed grows. This leads to reduction of range of speeds. If at 14,000 m. the range of speeds is 1[illegible] km/hr, at 15,000 m. it will be 134 km/hr at 18,000 m. - 113 km/hr and at 19,500 m. - 7[illegible] km/hr.

It is characteristic of this aircraft that at altitudes close to the ceiling the aircraft, having very wide range of speeds, flies at speeds, considerably exceeding the evolution one. Due to this the aircraft flying at these speeds is stable enough, well controllable and responds to the controls without much delay.

When the aircraft is climbing to the ceiling at M = 1.6, it will reach 19,500 - 19,900 m. at IAS = 6[illegible] - 6[illegible] km/hr. In the process of climbing back pressure is always applied to the stick and its load is relieved by means of the "trimming effect" mechanism.

In order to reach the ceiling the pilot must strictly adhere to the condition of climb (M = 1.6), as in case of deviation from this condition, the thrust surplus drops sharply and the aircraft does not attain the design ceiling or climbing is performed at low rates of climb.

It must be taken into account, that in case of the MiG-21-13 aircraft it is easier to maintain the given condition of climb than to recover it again as the latter will require great deflections of the controls. If the pilot [illegible]

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maintains the given condition of climb to the ceiling, then at the ceiling the aircraft will have 3 [illegible] - 1 [illegible] lit. of fuel left. If take-off and climbing are performed at afterburner power setting, at the ceiling the amount of fuel left will be only 4[illegible] - 5[illegible] lit.

One of the indications of aircraft flight characteristics deterioration in stratosphere is the decrease of maximum G-load value which leads to considerable increase of radius and duration of turn.

Fig.41 displays maximum net G-load values in stratosphere during execution of steady turns.

At medium and high altitudes the maximum net G-load may exceed the maximum permissible one; in this case it is limited by the aircraft structural strength as well as by pilot's ability to withstand G-load. In stratosphere and particularly at altitudes close to the ceiling these limitations are ineffective and G-load value is limited by full travel of the stabilizer.

Due to its wide range of speeds the aircraft can perform maneuvering at altitudes close to the ceiling (18,5[illegible] - 19,5[illegible] m.) with fairly steep banks (in the order of 3[illegible] - 4[illegible]). In this case radius of turn at M = 2, will be [illegible] km., and 18[0] turn duration - 5.5 min. It should be taken into account that banks are easily established, but G-load is not suitable for execution of a coordinated turn, therefore, turn is performed with a considerable loss of altitude.

While executing 18[0] turn to return to the airfield, it is more advisable to lose some time and carry out a shallow turn, than to resort to steep banked turn entailing great loss of altitude and high rate of descent. In the latter case, the aircraft loses much of its altitude while the distance to the airfield remains almost the same.

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Dynamic Altitude Flying

At the ceiling or at altitudes close to the ceiling the supersonic aircraft possesses considerable kinetic energy which can be used to climb to fairly high additional altitude in the course of execution of a vertical maneuver (zoom).

In connection with this, alongside with the aircraft static ceiling concept, dynamic flight altitudes concept and maximum dynamic flight altitude concept came into being as the attainment of these altitudes is connected with execution of a maneuver.

The dynamic flight altitudes mean altitudes which exceed the aircraft static ceiling and at which level flight is possible only at the expence of gradual reduction of speed to a certain minimum after which the aircraft assumes descending attitude due to lack of speed.

Maximum dynamic flight altitude is called an aircraft dynamic ceiling. This ceiling, like any other dynamic flight altitude, is attained during execution of zoom when the latter is entered at high (maximum) flying speeds at altitudes considerably lower than the ceiling of the aircraft.

It is quite obvious that the attainable dynamic flight altitude essentially depends not only on zoom entry speed but on zoom recovery speed as well.

In order to determine the potentialities of the aircraft to climb to dynamic flight altitudes, let us examine the components of the energy of the flying aircraft.

Total mechanical energy of the flying aircraft is made up of two energies: potential one (energy of altitude of flight) GH and kinetic one (flying speed energy) $\frac{GV^2}{2g}$.

Thus, the total mechanical energy of the flying aircraft is found from the equation

$$E = GH + \frac{GV^2}{2g},$$

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where G is aircraft weight;

V - flying speed;

g - gravitational acceleration.

It is more convenient to analyze not the energy of the whole aircraft but the energy of 1 kg of it, i.e.,

$$e = H + \frac{V^2}{2g}.$$

If engine thrust exceeds drag, total energy of the aircraft in flight increases as either altitude or flying speed augments, and vice versa, if drag exceeds thrust, total energy of the aircraft diminishes as the aircraft loses either speed or altitude.

In case of equilibrium of thrust and drag forces, the total mechanical energy of the aircraft remains constant. In this instance, however, the energy of altitude may transform into the energy of speed and vice versa, i.e., altitude can be gained at the expense of speed loss, and speed can be increased at the expense of altitude loss.

Graphic dependence of aircraft speed upon altitude at equilibrium of thrust and drag forces (when the total mechanical energy of the flying aircraft is maintained constant) is represented by a parabolic line, along which the aircraft energy remains constant (Fig.42).

Each value of the aircraft energy has its own parabolic line.

Let us draw the MiG-21-15 aircraft minimum and maximum speed curves on the grid of lines of equal energies. These curves will represent the boundaries of possible steady conditions of flight. Inside the area, thrust may be either higher or lower than drag and depending on engine power setting, the total energy of the aircraft either increases or decreases. The aircraft can attain any line of equal energies, crossing the area of possible steady speeds of flight. The aircraft

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energy will be maximum at the point where one of the lines of equal energies and maximum speed curve meet.

Whatever maneuver or engine power setting may be, the aircraft cannot obtain total energy exceeding e_{max}.

The altitude, at which the speed along e_{max} line becomes equal to minimum speed, lies above the aircraft static ceiling and constitutes maximum dynamic flight altitude or aircraft dynamic ceiling (point [illegible] in Fig.42). Thus, the area, limited by the maximum and minimum speed curve and e_{max} maximum energy curve represents an area of dynamic flight altitude of flight.

Flying, in this case, is possible only for a short period of time and is accompanied by speed loss. The higher is the dynamic flight altitude the lesser will be eventual duration of flight at this altitude. At maximum dynamic flight altitude (at aircraft dynamic ceiling) eventual duration of level flight is equal to zero, as all (or almost all) reserve of kinetic energy has been spent on climbing and the aircraft does not possess energy to perform level flight.

To attain dynamic flight altitudes the pilot should execute zoom, selecting initial position at an altitude somewhat lower than the static ceiling, the maneuver entry speed being close to the maximum one at this altitude.

The value of elevation of actual dynamic flight altitude above the static ceiling depends upon the initial values of flying speed and altitude. The greater is the speed loss during execution of zoom, the higher will be the altitude the aircraft attains.

In order to attain a given dynamic flight altitude at maximum possible speed the pilot has to initiate zoom from a quite definite (optimum) altitude at which the total mechanical energy of the aircraft has its maximum value. For the [illegible] fighter this altitude will be approximately at 19,[illegible] - 19,200 m.

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Due to G-load at the beginning of zoom the aircraft leaves its flight path up. At altitudes above the ceiling and at G-load exceeding 1, engine thrust is lower than drag. Therefore, when the flight path tends up, the speed decreases both due to the fact that thrust is lower than drag, and due to the fact that weight component $G \sin \theta$ acts as braking force. Elimination of speed and air density entails G-load decrease and at a certain altitude exceeding the static ceiling, the aircraft returns to level flight possessing a certain speed.

Zoom recovery speeds vary according to the initial values of altitude and speed and flying procedures at various dynamic flight altitudes. Level flight and various evolutions (turns) can be performed at dynamic flight altitudes though they will be accompanied by speed decrease due to braking.

The aircraft can continue to fly at speeds depending on stalling speed, which is the minimum possible speed at level flight.

If at dynamic flight altitude the aircraft is not able to perform level flight, but starts descending right after reaching the required altitude, safe indicated air speeds, from the point of view of stalling, prove to be lower than level flight minimum speed. In these conditions the minimum speed is determined by efficiency of the controls. If the speed is sufficient, the pilot will be able to control the aircraft and the latter will follow the flight path chosen.

The altitude attained during execution of zoom depends not only on the initial altitude and entry speed but also on the maneuver termination speed and can be found from the equation

$$\Delta H = 4500 \left(M^2_{entry} - M^2_{recovery}\right),$$

where ΔH is altitude reached during zoom execution;

M_{entry} - zoom entry M-number;

$M_{recovery}$ - zoom recovery M-number.

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If the pilot, flying the MiG-21[illegible]-15 aircraft, executes zoom from the best initial position, which has maximum level of energy corresponding to it (entry altitude - 19,[illegible] m., n = 2.5), and the speed during execution drops to the minimum one (IAS = 21[illegible] - 215 km/hr), the altitude gained in the course of zoom will be about 95[illegible] - 1[illegible],[illegible] m., and the maximum dynamic flight altitude (dynamic ceiling) attained, will be 20,[illegible] - 20,5[illegible] m. During zoom execution with speed decrease up to the minimum one the pilot should remember, that the ailerons in this case become low-efficient (when IAS drops below 25[illegible] km/hr), and must check the aircraft tendency to bank by corresponding deflection of the rudder which still preserves its efficiency.

In order to attain dynamic flight altitude without losing speed below the evolution one, the pilot sends the aircraft into climbing by establishing a pitch angle of 12 - 15° and maintaining it with the help of the artificial horizon. In the process of climbing, when IAS reaches 37[illegible] - 3[illegible] km/hr, the pilot should smoothly decrease pitch angle so that zoom termination speed will be 35[illegible] - 36[illegible] km/hr. At this speed the aircraft is stable and fairly controllable, which allows the pilot to execute a coordinated turn, if necessary.

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Chapter V

COMBAT FORMATION FLYING

Group flying in combat formations is one of the complex components of fighter command flight training. The performance of a group flight depends on flight qualification of each pilot of the group and on efficiency of the leader to guide the group in flight. Efficient execution of a group flight largely depends upon thorough ground rehearsal of procedures and sequence of execution of all flight elements.

The following aspects should be attended to in the process of pre-flight preparation:

(a) engine starting arrangements;

(b) sequence of taxiing to the runway and stacking of aircraft on the runway prior to take-off with due allowance to wind direction;

(c) procedure and sequence of take-off;

(d) join-up procedure;

(e) procedure and sequence of execution of flight elements;

(f) procedures of formation changing and break;

(g) emergency procedures.

In order to enable the wingmen to keep their positions in the formation the leader must competently select flight condition and engine power setting; change engine r.p.m. smoothly, avoid sharp evolutions of the aircraft, which may endanger flight safety; ably estimate the aerial situation; issue timely, clear and concise commands. The wingmen should firmly know the particular features of flying under various conditions and at various speeds and altitudes.

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Flying in Pair

During execution of flights in pair the pilots are to perfect: stream take-off and take-off in pair, climbing, formation joining and changing procedures, straight flight at constant and variable speeds, turns and banked turns, diving, zoom, chandelles, spirals (at subsonic and supersonic speeds), gliding and break for landing procedures.

The characteristic feature of a group flight executed on the MiG-21 -13 fighter consists in deterioration of visual control of the wingman by the leader wearing a pressurized helmet.

The pair can fly in close and extended combat formations, though the close combat formation of the pair is to be practised only at subsonic speeds and at altitudes up to 12,000 m.

The pair of MiG-21-13 aircraft uses echelon formation with 2[illegible] - 3[illegible] m. interval and 5[illegible] - 7[illegible] m. distance as its close combat formation.

In extended combat formation the aircraft can adopt either echelon formation with 5[illegible] - 8[illegible] m. interval and 2[illegible] - 3[illegible] m. distance or line abreast formation with 1[illegible] - 15[illegible] m. interval and 1[illegible] - 5[illegible] m. distance. In all combat formations the wingman must always be 5 - 10 m. lower than the leader.

Stream take-off. The wingman follows the orders of the leader for engine starting and taxiing. On getting and officer clearance for taxiing the leader and the wingman start taxiing, enter the runway and stack the aircraft in echelon with 20 - 3[illegible] m. interval and 3[illegible] - 4[illegible] m. distance. In case of crosswind the wingman's position must be up-wind.

On entering the runway the leader and the wingman taxi the aircraft down the runway to align the nose wheels with the latter, bring the aircraft to a standstill and proceed with cockpit preparations required for take-off. After making sure that the wingman is ready for take-off, the leader requests clearance for take-off. On being cleared, he follows the prec-

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dure used for a single aircraft take-off. As soon as the leader starts rolling, the wingman increases engine r.p.m. to 1[illegible] percent holding the aircraft in position by means of the brakes and then commences take-off on command of the AFC officer.

The stream take-off procedure is used in the initial period of training or due to runway limitations, as well as in case of a strong crosswind.

The wingman is advised to join the leader from any [illegible] take-off leg prior to crosswind turn or from circuit inner [illegible] after the downwind turn if approved by the leader.

While joining the formation the pilot must remember that the aircraft is very sluggish.

At the beginning of joining, the wingman establishes somewhat increased interval (5[illegible] - 8[illegible] m.) and altitude separation (15[illegible] - 2[illegible] m. lower than the leader) and then takes his position in the combat formation.

The pilot must take into account the fact that if he flies strictly behind the leader and at the same altitude he will have poor observation of the leader, particularly when looking through the windshield, due to thin wing profile of the "MiG-19 aircraft. The observation improves if the wingman takes his position to the side and somewhat lower than the leader.

Take-off in pair. The wingman follows the ordders of the leader for engine starting and taxiing. While taxiing the wingman must maintain such interval and distance which enable him to avoid the jet of the leader.

On entering the runway the wingman arrangues his aircraft parallel to the leader, takes it down the runway to set the nosewheel neutral and lines it up at 30 m. distance and 3[illegible] m. interval from the leader.

After the aircraft comes to a standstill the pilot proceeds with cockpit preparations required for take-off, but the nose wheel brake will not be turned on. The latter is turned on right after retraction of the landing gears.

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After making sure that the aircraft are properly lined up and after being advised by the wingman that the latter is ready for take-off the leader requests clearance for take-off. Then cleared, he smoothly increases r.p.m. to 97 - 98 per cent, orders the wingman to take-off, releases the brakes and commences to roll. In the process of roll r.p.m. are increased to 100 per cent. The leader raises the nose wheel at a speed 10 - 15 km/hr higher than that used during single aircraft take-off.

After reporting the leader on his readiness to take off, the wingman applies brakes, increases r.p.m. to 97 - 98 per cent and attentively watches the leader. As soon as the latter starts to roll, the wingman releases brakes and starts to roll.

He maintains the distance at take-off by changing engine r.p.m.; during the initial roll the interval is maintained with brakes, then - with rudder only.

In the second half of the roll, the wingman must maintain the given interval and distance and pay due attention to raising the nose wheel of his aircraft, avoiding to raise it earlier than the leader does. He starts to raise the nose wheel following the leader. Unstick of the aircraft is executed independently. The wingman follows the leader in retracting the landing gears and flaps after the aircraft has assumed climbing attitude.

Take-off from an unpaved runway having even surface does not differ much from that performed from a concrete runway. If the unpaved runway has rough surface, the aircraft at take-off will experience rocking and rolling which make it difficult for the pilot to maintain directional control, the given interval and distance and to raise the nose wheel at a proper moment. In this case take-off in pair will not be executed.

Characteristic errors in execution of take-off in pair.

The most characteristic error in execution of take-off in pair is failure to maintain a given distance at take-off roll. If at the beginning of take-off roll the wingman notices that

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he is catching up with the leader, he must reduce r.p.m. and then increase them again to the initial one as soon as he notices that outrunning has stopped.

If the wingman has overtaken the leader, he should increase r.p.m. to maximum ones and continue to take off independently, strictly maintaining directional control. After assuming climbing attitude the wingman must smoothly execute outward turn of 10 - 15°, immediately decrease engine r.p.m. and, on detecting the leader, join him in straight flight, if the leader agrees of the maneuver.

In case of lagging at take-off run the wingman has to increase r.p.m. to maximum ones. If lagging still remains he will continue take-off keeping the leader aircraft in sight and maintaining safe interval to avoid the jet of the leader. Raising of the nose wheel and unstick are performed in this instance independently. After the landing gears have been retracted and the aircraft has assumed climbing attitude, the wingman requests clearance to join the leader and joins him in straight flight.

Climbing

The pair of MiG-21F-13 aircraft can climb in close and extended combat formations at the best climbing speed and at normal, full thrust and afterburning power settings.

In the initial period of group flight training climbing is performed at normal power setting. The wingman maintains the given distance by changing engine thrust or by extending the air brakes, and the given interval by operating the rudder.

If it is necessary to attain the given altitude in minimum possible time, the aircraft will climb at full thrust or afterburning power setting.

Extended echelon formation with 50 - 80 m. interval and 200 - 300 m. distance will be most advisable for climbing.

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If it becomes necessary to switch on afterburner the leader will instruct the wingman GET READY FOR AFTERBURNER SWITCHING ON, then order AFTERBURNER. On this command the leader and the wingman simultaneously switch on afterburners. If the wingman begins to approach the leader rapidly due to disparity in switching-on of the afterburners, he must immediately extend the air brakes. If the wingman starts lagging he should advise the leader on the fact and the latter will extend the air brakes to recover the given distance.

Level Flight.

Level flight in pair on the MiG-21-15 aircraft at all power settings and at all speeds and altitudes presents no problem.

The wingman maintains the given distance by changing engine thrust and by applying the air brakes. If after wingman's radio report it becomes necessary to recover the given distance the leader will also resort to engine power variation and brakes. The given interval in close combat formation at subsonic speeds is maintained by means of the pedals and in extended combat formation (at all speeds) - by coordinated movement of the stick and pedals.

When flight is carried out at full thrust and afterburning power settings, the given combat formation is maintained by application of the air brakes by the leader and by the wingman and by execution of snaking in horizontal or vertical plane.

If in spite of all attempts the combat formation cannot be preserved, it will be necessary to set normal [illegible] power.

Resetting the afterburning and full thrust power, or full extension of the air brakes the leader [illegible] by the leader.

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Horizontal Plane Maneuvering of Pair Flying in Close Combat Formation

Turns and banked turns to leader's side. Prior to execution of turn the leader establishes a required speed, advises the wingman on direction of turn and smoothly enters the turn. On receiving order from the leader and watching attentively the maneuvering of the latter, the wingman commences the turn, following the procedure used by the leader, and at the same time increases engine r.p.m. and assumes the station above the leader and in the same plane.

In the course of turn (banked turn) the wingman maintains the interval by changing bank value and by rudder deflection, and the distance - by changing engine r.p.m. or by applying the air brakes. The wingman keeps his station within the same plane as the leader's by varying angular motion of his aircraft and by changing the bank.

Prior to turn (banked turn) recovery, the leader issues corresponding instructions to the wingman and smoothly commences turn recovery. The wingman executes turn recovery following the procedure used by the leader; during the recovery he should duely reduce engine r.p.m. to avoid overtaking of the leader. If during execution of turn or in the course of turn recovery the wingman drops the leader out of sight, he must leave the formation, heading outward and gaining altitude, and after detecting the leader will join the formation in straight flight if cleared by the leader.

Turns and banked turns to wingman side. Prior to execution of turn, the leader establishes a required speed and advises the wingman on direction of turn (banked turn). On receiving order from the leader the wingman enters the turn, following the procedure used by the leader, and at the same time reduces engine r.p.m. keeping the station of his aircraft in the same plane as the leader's.

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For maintaining the combat formation the same procedure is used as in case of execution of turn to leader's side.

If instructed to recover from the turn, the wingman synchronizes reduction of bank with the leader and at the same time increases thrust and assumes the given position below the leader.

The pair, flying in close combat formation, executes turns and banked turns at engine power settings not exceeding normal rated thrust power.

Formation changing. Pair formation changes, entailing only distance and interval changes, are executed on leader's instruction, the distance being changed by momentary variation of thrust or by extension of the air brakes, and the interval - by deflection of the rudder and ailerons.

Formation changes entailing transition from echelon right to echelon left and vice versa are performed also on leader's instruction or on wingman's request.

For changing close formation from echelon right to echelon left or vice versa, the wingman, by applying the air brakes and reducing engine thrust, increases distance to 1[illegible] - 15[illegible] m. and at the same time augments altitude separation to 3[illegible] - 4[illegible] m. (below the leader), then by coordinated movements of the pedal and stick changes its station in the formation, keeping the leader in sight.

After establishing a somewhat increased interval of 5[illegible] - 7[illegible] m. he attains a given distance and altitude separation, then smoothly using the pedals establishes 2[illegible] - 3[illegible] m. interval.

Procedure of formation changing when the aircraft are flying in extended combat formation is similar to that described above though in this case preliminary leading is not necessary. While changing formation the wingman should avoid the wake of the leader's aircraft.

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Horizontal Plane Maneuvering of Pair Flying in Extended Combat Formations

The pair, flying in echelon extended combat formation, can perform turns and banked turns at subsonic and supersonic speeds; the turn may be directed either to the leader's side or to the side of the wingman. While executing turns the wingman is to fly his aircraft in the plane different from the leader's but their altitude must be the same. In this case he maintains the distance by means of the air brakes and the interval - by bank change.

There are two methods to perform a turn (banked turn) directed to leader's side:

(a) the wingman enters the turn, following the procedure used by the leader, and at the same time reduces the interval to an extent to plan turn recovery with the same radius as that of the leader and with altitude separation (below the leader) which enables him to avoid the wake of the leader's aircraft;

(b) the wingman and the leader enter the turn simultaneously but the former, by establishing a somewhat steeper bank changes the echelon and after attaining a given interval executes the turn as an inward wingman maintaining the distance by means of the air brakes and the interval - by means of coordinated movements of the ailerons and rudder.

Vertical Plane Maneuvering

The pair will be allowed to perform vertical plane maneuvers only after it has successfully mastered horizontal plane maneuvering in close and extended combat formations.

Maneuvers executed in vertical plane include: diving, zooms and chandelles. Practising of these maneuvers should begin with diving and then proceed to zooms and chandelles.

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Vertical maneuvers can be performed by the pair flying either in close or extended combat formation.

Diving. Diving can be initiated either from a straight flight or from a turn.

While entering dive from a straight flight the leader must fly the aircraft so, as to prevent occurrence of negative g-load. The aircraft must enter the dive smoothly so that the wingman might keep his station in the combat formation and should not occur to be above the leader during dive entry.

In diving, the leader plane reduction of his engine power in a way to leave the wingman a margin enabling the latter to keep his station in the combat formation.

At dive entry the wingman establishes altitude separation of 5 - 7 m. below the leader and maintains this altitude till dive recovery.

Dive recovery is accomplished by smooth application of back pressure to the stick with simultaneous augmentation of engine thrust to the required one. In dive recovery the wingman follows the procedure used by the leader giving his attention to maintaining of the given distance and interval.

Dive can be initiated out of a turn at any power setting but with extended and retracted air brakes. After setting the required power the wingman smoothly enters the turn in horizontal plane and subsequently assumes descending attitude.

In the course of the turn angle of dive is increased to the given one.

If dive is initiated out of a turn executed in the direction of the leader, at the beginning of the turn the wingman has to fly at the same altitude as the leader, but in the second half of the turn he should establish altitude separation of 5 - 7 m. below the leader and maintain this attitude throughout the whole process of diving.

If dive is initiated out of a turn executed in the direction of the wingman, the latter has to fly in the same plane as the leader during the first half of the turn and [illegible]

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establish altitude separation of 5 - 7 m. below the leader by the moment the aircraft enters the straight leg of diving.

In diving the wingman maintains the distance by changing engine thrust and by application of the air brakes. The interval between the aircraft executing dive in close combat formation is maintained by rudder deflection, while the interval between the aircraft performing dive in extended combat formation is preserved by coordinated operation of the rudder and ailerons.

Zoom. The pair can execute zoom at any engine power setting and at entry speed not exceeding the speed permissible for the given altitude.

Entry speed required for zoom execution can be obtained either by acceleration during shallow descent (10 - 15°) or in the course of diving.

During execution of zoom in close combat formation, the leader after setting a given speed, sends the aircraft into climb at a given angle, increasing r.p.m. to 97 - 98 per cent.

Watching the leader closely, the wingman enters zoom, maintaining the given altitude separation of 5 - 7 m. below the leader by changing the angle of climb, the interval - by rudder operation and the distance - by changing engine thrust or by applying the air brakes.

When the speed drops to zoom recovery speed which must not be less than 5[illegible] km/hr, if angles of climb are equal to 50 - 60°, and not less than 45[illegible] km/hr, if angles of climb are shallower than the above mentioned ones, the leader smoothly enters a turn, then gradually returns the aircraft to level flight. If angle of climb does not exceed 20°, recovery can be performed by straight pull-out, though durable and high negative G-load must not be allowed. The speed at which the aircraft returns to level flight must not be lower than 4[illegible] km/hr.

While executing zoom recovery the wingman follows the procedure used by the leader. If flight is carried out in close combat formation the wingman performs zoom recovery by executing a turn in the same plane as the leader.

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When extended combat formations are used, it is advisable to accomplish room recovery by executing a turn in the direction of the wingman. The latter performs the turn in the same plane as the leader. If it is necessary to perform room recovery by executing a turn in the direction of the leader, the wingman decreases the interval with the beginning of leader's turn and augments altitude separation to 2[illegible] - 3[illegible] m. below the leader, trying to maintain his radius of turn similar to that of the leader.

If the aircraft having uncontrollable thrust at afterburning power setting are flying in extended combat formations, the distance between the aircraft is maintained by application of the air brakes both by the wingman and by the leader.

Chandelle. The pair can execute chandelle at normal, full thrust and afterburning power settings and at entry speed not exceeding maximum permissible at the altitude of maneuver entry.

Acceleration of the aircraft to obtain entry speed can be performed either during descent (angle of descent 1[illegible] - 1[illegible]°) or during diving.

To execute chandelle, the leader, after setting the given speed at 97 - 98 per cent of r.p.m. in level flight, establishes angle of climb of 1[illegible] - 2[illegible]° and enters the turn planning that recovery speed be not lower than 4[illegible] km/hr and the bank does not exceed 6[illegible] - 65°.

If the chandelle is executed in the direction of the leader by the aircraft flying in close combat formation, the wingman, closely watching the leader's maneuvers, enters the chandelle and carries it out in the same plane in which the leader's aircraft flies. He recovers from the chandelle following the instruction and procedure of the leader.

During execution of the chandelle the wingman maintains the distance between the aircraft by changing engine thrust or by applying the air brakes, while the interval is [illegible] by variation of bank and angular rotation, and the attitude [illegible]

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the aircraft in the same plane - by reduction or augmentation of angular rotation speed of the own aircraft.

The chandelle executed in the direction of the wingman is performed by the leader in the plane in which the leader's aircraft flies and the procedures used to keep the station in the formation are similar to those followed during execution of the chandelle in the direction of the leader.

Spiral

45° bank spiral can be performed both in close and in extended combat formations.

When executing spiral in close combat formation, the leader, while descending, selects r.p.m. enabling the wingman to keep his station in the formation, sets a required speed and then smoothly enters the spiral.

Keeping the leader in sight, the wingman enters the spiral also and maintains the interval by bank variation and the distance - by changing engine thrust or by applying the air brakes.

He keeps his aircraft in the plane in which the leader flies, by varying angular rotation speed of his own aircraft.

To recover the aircraft from the spiral the leader has to recover it from the bank first and only after that he establishes a required condition of flight.

Extended combat formation spiral executed in the direction of the wingman will be performed by both aircraft in the same plane and that executed in the direction of the leader will be performed by both aircraft at the same altitude.

Descent

The pair descends from high altitudes in close or in extended combat formations using spiral or diving procedures at normal rated thrust or lower power settings with or without application of the air brakes.

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While descending with extended air brakes the leader must not reduce r.p.m. to minimum once permissible at this altitude. The speed of the aircraft in descent should not exceed maximum permissible once rated according to altitudes.

Break for Landing

Prior to breaking the group for landing, the leader changes the group formation into echelon right or echelon left according to the airfield traffic pattern, guides the group to approach the airfield with landing course and flies over the airfield outside the traffic circuit and parallel to the runway. After getting ATC clearance for landing, he orders the group to break off and executes 90° turn to join the traffic circuit. The wingman continues to fly straight forward during a certain period of time corresponding to the half of the safety time interval between aircraft landings, and then executes 90° turn. After break off pilots plan their circuit flying and landing independently.

Flying in Pair at Altitudes Close to Aircraft Ceiling

Flying in pair at altitudes close to the aircraft ceiling is of more complicated nature than that executed at medium and high altitudes and possesses certain distinguishing features.

Complicacy of flight execution at ceiling altitudes is explained by:

(a) deterioration of aircraft maneuverability;
(b) augmentation of aircraft sluggishness;
(c) deterioration of stability;
(d) high angles of pitch due to high angles of attack;
(e) reduction of air brakes efficiency;
(f) leader's limitations to control the wingman visually;
(g) poor visibility of the natural horizon.

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Taking into account all these factors the leader has to issue concise and timely orders for execution of maneuvers and to handle the controls smoother during execution of these maneuvers.

The wingman must follow the leader's evolutions more attentively, timely respond to these evolutions and say the leader's instructions back.

It is advisable to use extended combat formations while flying at ceiling altitudes.

The combat ceiling of the pair is an altitude which is 300 - 500 m. lower than the combat ceiling of a single aircraft.

Section Formation Flying

The section is allowed to proceed to section formation flying only after it has successfully accomplished flight training in pair. The pair can operate in echelon and pairs in line astern close and extended combat formations.

While flying in close combat formation the second pair has to maintain 50 - 70 m. distance, 20 - 30 m. interval and altitude separation up to 20 m. (below the first pair).

When the flight is executed in extended combat formation, the distance is augmented to 300 - 400 m., the interval - to 100 - 150 m. If the pairs in line astern combat formation is used, the distance between the pairs must be 500 - 700 m., and the altitude separation - up to 100 m. (below the leading pair).

Depending on flight qualification of the pilots the section can perform stream take-off, pair take-off or section take-off.

Otherwise, the wingman will find little distinction in section formation flying as compared with flying in pairs, though it must be remembered that section flying requires more accuracy in aircraft flying and higher degree of look-out.

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A section of the MiG-21F-13 aircraft, flying at subsonic speeds, can execute the same maneuvers as performed by the pair.

Flying at Transonic and Supersonic Speeds

Execution of a group flight at supersonic speed contains a number of distinctions concerning flying technique, as the pilot flying an aircraft the thrust of which is uncontrollable at afterburning power setting is unable to keep his station in the formation by changing engine thrust at afterburning power setting.

Only those pilots are allowed to execute group flights at supersonic speeds who have acquired good qualification in single aircraft flying at supersonic speeds and have undergone sufficient training in execution of group flights in close and extended combat formations at subsonic speeds.

If a group flight at supersonic speed is performed by aircraft the thrust of which is uncontrollable at afterburning power setting, the combat formation can only be preserved by application of the air brakes both by the leader and the wingman.

The leader is usually late in noticing the wingman's dropping behind and in most cases applies the air brakes to recover the distance only after the wingman has advised him on his lagging.

In case aircraft with uncontrollable thrust at afterburning power setting are used, execution of a group flight at supersonic speed will require that the leader should fly an aircraft possessing lower thrust while the wingman should be given an aircraft developing higher power.

A given interval between the aircraft in a group flight at supersonic speed will be maintained by coordinated deflections of the ailerons and rudder.

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Execution of turns at supersonic speeds will be accompanied by interval reduction or even by aircraft station change in the course of the maneuver.

In addition to the above mentioned distinctions in flying technique a characteristic feature of a group flight at supersonic speed is occurrence of shock waves in aircraft wake which move together with the aircraft (Fig.43). Effect of shock wave of one MiG-21-13 aircraft on the other will be the same whatever speed the latter flies at: subsonic or supersonic.

When an aircraft which performs flight at subsonic speed is being overtaken at the same or somewhat higher altitude, at the very moment of overtaking the pilot of the aircraft which is being overtaken will feel two, following in quick succession, shocks on the pedals and shaking of the whole aircraft. If the aircraft is being overtaken from below the pilot will feel stronger shaking of the whole aircraft though there will be no effect on the pedals and stick. In both cases the pilot of the overtaking aircraft will experience no change in operation of the controls.

In case an aircraft, flying at supersonic speed, is being overtaken, the effect of shock waves will be mutual and the overtaking aircraft will also experience shaking of shock nature, whether it passes the other aircraft from below or by side.

The strongest effect of shock wave will be experienced when the overtaking aircraft flies 10 - 50 m. below the aircraft which is being overtaken.

When the vertical separation is increased to 100 m., shock wave effect diminishes considerably, and when an aircraft overtakes another aircraft with vertical separation being 150 - 200 m. and more, the pilot does not actually feel shock wave effect at all.

At the moment of shock wave effect the aircraft does not experience high G-load and shaking of the aircraft and shock felt on the pedals in no way interfere with aircraft flying.

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Thus, due to low intensity of shock waves originated by the MiG-21-13 aircraft flying at supersonic speed, the mutual effect of these waves on the aircraft during execution of group flights proves to be insignificant and presents no problem in execution of flight regardless of the distance between the aircraft.

Inasmuch as occurrence of shock waves during execution of flight at supersonic speed does not actually affect group flying, the principal factors influencing a given distance (interval) between aircraft in the group remain the same for supersonic flight as for subsonic one.

Formation changing will be more complicated to perform at supersonic speeds than at subsonic speeds.

Due to the fact that aircraft flying in combat formations at supersonic speeds maintain increased intervals and distances, formation changing will not require distance changes.

Changing from echelon right into echelon left and vice versa must be executed with a bank up to 2[illegible]° and altitude separation up to 2[illegible] - 3[illegible] m. (below); only in this way the pilot can easily change from one echelon into the other one.

It is a great problem to maintain given distances between aircraft during section formation or larger group formation flying at supersonic speeds. Therefore, combat formation of a group of fighters flying at supersonic speed has to be narrow in front and extended in depth.

The MiG-21-13 aircraft is provided with a system enabling the pilot to adjust engine thrust at afterburning power setting from MINIMUM AUGMENTED ([illegible]) to FULL AUGMENTED (ПОЛНЫЙ ФОРСАЖ) which presents wider potentialities for combat formation manouvering of the fighters.

While training pilots in group flying the leader is advised to fly at afterburning power setting with the engine control lever being in position MINIMUM AUGMENTED; this arrangement enhances chances of the wingmen to keep their stations in the formation.

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While flying the MiG-21F-13 aircraft the pilot has to take into account certain distinguishing features of engine control.

When the pilot retards the engine control lever from the FULL AUGMENTED position to the MINIMUM AUGMENTED position with the afterburner control lever being pressed, he may accidentally pull the lever behind the engine maximum thrust detent and afterburner will cut off. To avoid it, the pilot is advised to release control lever after the lever has disengaged from the afterburner stop and is pulled back.

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Chapter VI

FLIGHTS IN ADVERSE WEATHER CONDITIONS

Requirements of training syllabus must be strictly adhered to, when the MiG-21F-13 pilots are being trained for flights in adverse weather conditions.

While practising flights in adverse weather conditions, flight personnel of the MiG-21F-13 aircraft will encounter certain distinguishing features in training procedures and planning of flights.

Training of flight personnel of the MiG-21F-13 aircraft for flights in adverse weather conditions must consist of ground and flight training.

Ground Training

In the course of ground training for flights in adverse weather conditions the flight personnel has to get thoroughly conversant with:

(a) flight and navigation instruments and other special equipment of the aircraft which enables the pilot to execute flights by employing various landing systems;

(b) upward and downward cloud penetration conditions noted for the MiG-21F-13 aircraft and procedures of flying with aids of landing systems available at a given airfield.

While studying flight and navigation instruments and other special equipment of the aircraft the flight personnel should, first of all, get to know thoroughly the instructions on operation of the equipment on the ground and in flight.

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The pilot must firmly know every instrument for its multiplying factor, rules to take readings and range of readings, permissible and actual errors for this particular specimen of the instrument, position of the instrument pointers at established and maximum permissible conditions of flying, procedures to switch the instrument on and to check its operation on the ground and in flight, instrument failure indications, rules to interchange instruments in flight and procedure to fly the aircraft using doubling instruments.

Special attention has to be paid to those instruments which are new to the pilot.

While studying the cockpit the pilot must pay due attention to layout of instruments on the instrument panel and to distribution of all equipment used in flight.

The pilots should bear in mind the fact that aircraft of different versions as well as aircraft of the same version but of different series may differ in layout of instruments on the instrument panel and in distribution of equipment in the cockpit.

In the course of studying cloud penetration conditions, the flight personnel must get to know firmly attention distribution order at each stage of flight, causes which induce errors in maintaining given conditions of flight and procedures for correction of these errors, steps to be taken to increase accuracy of navigational flying, emergency procedures and other pertinent measures providing for safety of flying in adverse weather conditions.

Besides, during ground training the pilot has to acquire habits in determining aircraft attitude by instrument readings, in distributing his attention and movements in flight by means of rehearsing them in the cockpit on the ground.

In the course of cockpit training the main attention will be paid to acquiring firm habits in focusing pilot's attention on the instruments while flying in adverse weather conditions, as applicable to the MiG-21F-13 aircraft, and to

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procedures followed in emergency when danger to safety of flying is imminent.

When conducting cockpit training, the commanding officer (instructing pilot) must pose pertinent questions and problems before the pilot, and the latter has to perform corresponding operations prescribed by the instructions on aircraft operation and required by employment of established procedures of cloud penetration, approach and judgement for landing and by usage of radio navigational facilities available at a given airfield.

The procedure of preliminary and pre-flight preparation for flying the Mig-21 -15 aircraft in adverse weather conditions does not differ at all from an ordinary pre-flight preparation procedure.

Flight Training

Flights and preparation of flight personnel for flights in adverse weather conditions have to be planned so that training of pilots is carried out during a certain period of a year and without interruption in their flying under adverse weather conditions on the aircraft they have mastered before.

Prior to proceeding to flights in adverse weather conditions the pilot has to perform at least three flights in visual meteorological conditions to practise straight-in and train 180° turns procedure for approach and judgement for landing with implementation of landing systems as well as to execute one flight to practise PP approach procedure.

During these flights the pilot gets conversant with instrument readings at different stages of flight and acquires habits to control the aircraft while maintaining given conditions of flight.

In the initial period of flying in adverse weather conditions in the daytime the pilot will carry out first two or three flights when cloud base is not lower than 500 m. and the

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proceed to flights in weather when cloud ceiling is lower than 500 m., as stipulated by the training syllabus.

While analysing weather conditions prior to allowing the pilot to perform his first flight in adverse weather conditions the commanding officer has to take into consideration not only 500 m. cloud base but also thickness of the layer, turbulence, icing conditions and visibility in, above and particularly below clouds.

All the process of flight training is planned with allowance for the fact that the [illegible]-21[illegible]-15 trainer is not available.

Therefore, in case of necessity, the [illegible]-15 trainer can be used for coaching and checking the operations of the pilot in flight.

After acquiring habits in performing single aircraft flying the pilot will proceed to flying in pair provided corresponding weather conditions are available and then to the [illegible]-21[illegible]-15 aircraft section formation flying.

Single Aircraft Flying

The following is a description of procedures followed by the pilot while performing single aircraft cloud penetration with usage of [illegible] landing system, ground [illegible] station and [illegible].

Prior to take-off the pilot has to check flight and navigation instruments and other special equipment, to perform all required operations for switching on all the necessary instruments and to make sure that the instruments are operative and read true.

Before starting the engine he sets the altimeter and checks whether altimeter readings and barometric pressure do coincide; in case of discrepancy he must unlock the [illegible] and lock it again after setting required pressure. The course-setter dial must read landing course.

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After external power has been switched on, the pilot closes circuit breakers and checks operation of the artificial horizon, compass, turn indicator, radio altimeter, pitot-static tube heating, then turns on the automatic radio compass and checks if they are properly tuned to outer and inner markers of the airfield of departure, sets the safe altitude indicator and checks operation of the radio altimeter. The pilot must bear in mind that when the drop tank is installed, the radio altimeter indicator pointer fluctuates between 7 and 1[illegible] - 3[illegible] m. and the given (unsafe) flight altitude signal will operate inadvertently, due to false signal. Then the pilot requests clearance to start the engine.

After the engine has been started, warmed up and tested, the pilot checks operation of the main and servo hydraulic systems, flaps, the compass and starts taxiing to the runway.

Take-off, Upward Cloud Penetration and Flying to I.F.R at Given Flight Level

After being cleared by the officer the pilot enters the runway, aligns the aircraft with it and makes sure that take-off heading and relative bearing read true; then he turns on the pilot-static tube heating, and stopwatch and performs take-off.

When airborn and after retracting the landing gear and flaps, before entering the cloud, at an altitude not lower than 2[illegible] m., the pilot checks if artificial horizon and turn indicator readings correspond to actual attitude of the aircraft relative to the natural horizon and makes sure that these instruments operate properly; for this purpose he rocks the wings establishing banks of 15 - 20°.

After making certain that the instruments read true, the pilot proceeds to IFR flying and sends the aircraft into climbing. Passing upward penetration of clouds, [illegible] flying at normal rated and full thrust [illegible] - 9[illegible] km/hr.

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After the pilots have acquired experience in cloud penetration at the above mentioned power settings, they may proceed to practising cloud penetration upward at afterburning power setting, which allows to take maximum advantage of combat abilities of the aircraft on air target interception missions.

For the purpose of timely detection of artificial horizon errors, the pilot must periodically check its readings by comparing them with the readings of the turn and slip indicator, rate of climb indicator and compass.

The speedometer thin pointer must always read 95 km/hr, when the aircraft flies climbing path before reaching the flight level.

When in the process of climbing the engine power setting is kept constant and IAS on the climb path is maintained 950 km/hr, the rate of climb, after reaching its maximum value, will start to drop uniformly while climbing continues. Angle of climb is similarly changed in the process of climbing.

Efficiency of flying in clouds, adherence to a specified condition of flight and safety of flying depend largely upon efficient distribution of pilot's attention when watching instruments.

The diagram of distribution of pilot's attention when watching instruments in climbing is displayed in fig.44.

Table 8 gives climbing characteristics of the aircraft flying with and without a drop tank.

Table 8

Altitude, m.	With drop tank		Without drop tank	
	time, min.	distance, km.	time, min.	distance, km.
1000	1.35	10	1.15	5
5000	2.70	30	2.50	25
10,000	5.75	80	4.90	65
11,000	7.10	100	5.85	80
12,000	9.30	130	7.10	100

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After emerging from clouds, the pilot for some time (depending on visibility above clouds) continues instrument flying gradually taking the space in front into his view.

300 m. before reaching a given flight level he commences to assume level flight attitude. 6[illegible] km/hr IAS is set simultaneously with transition to level flight. The air brakes may be used to expedite aircraft slow down. The turn to fly LOM is executed with 30 - 45° bank at 6[illegible] km/hr IAS. The first half of the turn will be performed in horizontal plane while the rest 6 - 9° will be made with gradual climbing to the given flight level.

The diagram of distribution of pilot's attention when watching instruments during turn is displayed in Fig.45.

While executing the turn the pilot has to take into consideration increased efficiency of the ailerons and therefore must handle the control stick intelligently when entering and recovering from the turn or when correcting banks. On accomplishing the turn to LOM the pilot will fly LOM at the given flight level, maintaining zero relative bearing and 6[illegible] km/hr IAS. The method of distribution of pilot's attention when watching instruments during LOM level flight is shown in Fig.46.

Instrument Straight-In Approach and Judgement for Landing

After reaching the cloud top and accomplishing the turn to fly LOM, the pilot reports his altitude and heading to LOM to ATC officer and gets landing instructions from the latter. While flying to the so-called "funnel" above LOM it is necessary to maintain zero relative bearing more accurately.

It is known that when the aircraft is passing the [illegible] of LOM, the radio compass pointer tends to fluctuate [illegible] from zero relative bearing and returning to its initial position again, and only after the aircraft has covered a certain distance from LOM the pointer begins to read fairly

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18[illegible]° or about 18[illegible]° relative bearing. Taking into consideration fluctuations of the automatic radio compass pointer, the pilot must pass the "funnel", maintaining the heading accurately. At the moment when the radio compass pointer reaches 18[illegible]° or about 18[illegible]° relative bearing, the pilot starts the stopwatch, executes the calculated angle (γ) turn and reports the AN officer on LOM passing.

Landing inbound course turn point is reached by maintaining a compass heading equal to landing reciprocal magnetic course plus a calculated angle, by strictly controlling the time ($t_{l.f}$) of level flight; the above procedure is checked by means of LOM magnetic radio bearing.

Still air level flight time is given in table 9.

Table 9

Altitude, m.	2[illegible]	3[illegible]	4[illegible]	500[illegible]	600[illegible]	7[illegible]	8[illegible]	9[illegible]	1[illegible]
$t_{l.f}$, min., sec.	2.5[illegible]	3.1[illegible]	3.2[illegible]	3.3[illegible]	3.40	3.5[illegible]	4.	4.1[illegible]	4.1[illegible]

When the level flight time expires, the pilot performs a turn to landing course establishing 30° bank and losing 300 m. during the maneuver. In the process of the turn he sets 500 km/hr - IAS.

For entering the landing course with zero relative bearing, the pilot, by increasing or decreasing the bank, will plan the second part of the turn so that the automatic radio compass pointer and the course-setter pointer set to the landing course value reach the triangular index simultaneously. Such position of the pointers will imply that the aircraft has intercepted the landing course line in the direction of LOM (Fig.47).

If the automatic radio compass pointer moves to the triangular index too fast, the bank should be reduced but if the course-setter pointer travels too fast the bank will be increased.

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After intercepting the landing course, the pilot carries out level flight for 3[illegible] sec. During this time he lowers the landing gears and advises the AMC officer on interception of the landing course, maintaining all this time 5[illegible] km/hr IAS.

After 3[illegible] sec. he sends the aircraft into descent at [illegible] m/sec. rate of descent and 5[illegible] km/hr IAS. This condition of descent is maintained up to 2[illegible] m.

The diagram of distribution of pilot's attention when watching instruments during descent is displayed in Fig.48.

Errors committed in the course of interception of the landing course are corrected by a coordinated turn to a corresponding direction. For this purpose the pilot has to turn the aircraft to head to LOM (the automatic radio compass will come to rest under the triangular index) and after that he will determine direction and value of a coordinated turn through deflection of the course-setter pointer. A coordinated turn will always be made in the direction of the automatic radio compass pointer.

Correction of landing course interception error is displayed in Fig.49. In this case, the actual course exceeded the landing course by the moment of turn recovery. Therefore, the pilot has to turn the aircraft right (in the direction of the automatic radio compass pointer) by establishing a bank of 15 - 2[illegible]°. At this time the automatic radio compass pointer and course-setter pointer will displace to the left from the upper triangular index. At the moment when the automatic radio compass pointer reaches half the distance between the triangular index and the course-setter pointer, the pilot will stop continue the turn, recover the aircraft from the bank and proceed to descend straight forward with a new heading. The automatic radio compass pointer, at this time, will gradually approach the course-setter pointer. It means that the aircraft is intercepting the landing course line. When the angle between the pointers is 5 - 6°, the aircraft will be turned to

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the left and the pointers will come to rest under the upper triangular index.

So the aircraft has intercepted the landing course again and is heading to LOM.

On reaching 2000 m. the pilot establishes 15 m/sec. rate of descent by reducing angle of glide, and at the same time slightly engine r.p.m. to maintain 500 km/hr speed. At 1000 m. the rate of descent is further reduced to 10 m/sec., IAS being 500 km/hr. Beginning from 600 m. the pilot sets 5 m/sec. rate of descent, maintaining glide trajectory speed within 500 km/hr until the aircraft breaks through the clouds.

Transition of the aircraft to level flight condition to fly LOM will commence from 350 m. and will terminate at 300 m. Level flight speed below clouds will be set at 450 km/hr.

At the initial period of practising the AGK gyro and the compass flying during straight-in approach, the aircraft attitude relative to the landing course line (extension of the landing mark line) can be controlled and corrected by following this rule: the pilot mentally takes the automatic radio compass pointer for the aircraft longitudinal axis direction and the course-setter pointer for the runway (Fig.50).

In this case the pilot easily determines the aircraft attitude relative to the runway and the type of manoeuver to be performed to correct an error committed in selecting direction of approach.

While descending from high altitudes the pilot has to give most of his attention to maintaining lateral equilibrium of the aircraft, progressive speed and rate of descent following the direction indicated by the automatic radio compass and compass. Beginning from 1000 m. and down the pilot pays more attention to altitude change and to maintaining given conditions of descent.

The diagram of distribution of pilot's attention when watching instruments while descending from 1000 m. is displayed in Fig.51.

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During descent the pilot must strictly follow the landing course direction, with the relative bearing reading 0.

The pilot should remember the following rule: if the pointer reads zero relative bearing and the course-setter bar has deflected at a certain angle, the aircraft will be turned in the direction opposite to the course-setter bar deflection by double error value.

As soon as the automatic radio compass pointer reaches the course-setter bar, the pilot turns the aircraft to intercept zero relative bearing and the aircraft gets in line with the runway.

While descending the pilot has to take into account a crosswind factor.

If during passing LOM the radio compass pointer reads zero relative bearing while the magnetic course increases (the front part of the compass course-setter travels left), that implies that the aircraft is drifting left. The pilot can judge drift value by rate of course-setter deflection from the zero reading mark.

If in the process of descending to 1[illegible] m. the pilot fails to rectify the error committed during interception of the landing course, he must drop his attempts to match the compass and radio compass readings; in this case it is [illegible] to turn the aircraft to a corresponding direction to reduce the error by approximately 5° of the relative bearing (the latter will read 5° or 355°) and continue descent to 1[illegible].

After the [illegible] altitude warning unit has operated, the pilot discontinues descent, and returns the aircraft to level flight maintaining speed of 4[illegible] km/hr.

On reaching 3[illegible] m. he proceeds to LOM (relative bearing = 0) continuing instrument level flight. And only when visual check points become clearly visible, the pilot, continuing instrument flight, will [illegible] visual flight, i.e., [illegible] refuse to chase the [illegible]

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While approaching LIM the pilot will concentrate his attention on determining the moment of LIM passing. At the moment the aircraft enters LIM operation zone (this moment is indicated by illumination of the 1-4 LIMITS inscription and bell ringing), the pilot switches the automatic radio compass onto LIM executing (if necessary) at the same time according turn to LIM, gives full flaps, sends the aircraft into level planning to pass LIM at [illegible] - 1 [illegible] m. and at a speed of 3[illegible] - 360 km/hr, finalizes approach and judgement for landing and executes landing proper.

While penetrating the clouds upward at 72[illegible] km/hr speed (as indicated by the thin pointer) or performing level flight at 5[illegible] km/hr IAS or being let down at 45[illegible] km/hr speed to reach cloud ceiling, the "[illegible]" aircraft is stable and does not display essential distinction in its handling procedure as compared with the flight condition described above.

Twin 180° Turn Approach and Judgement for Landing Procedure with Employment of ODR Instrument Landing Facility

The pilot can use the twin 180° turn approach procedure either after take-off or after taking decision to go-around.

In case of go-around, the following approach and judgement for landing procedure will be used.

After the aircraft has stopped descending, the pilot retracts the landing gears and on reaching an altitude not less than 100 m. raises the flaps.

A specified altitude is climbed at 500 km/hr IAS and 10 m/sec. rate of climb.

When lock time to LOM is 1.5 min. or to LIM is 1 min., the pilot performs the first 180° turn at 500 km/hr establishing 30° bank. While executing 180° turn he must determine the recovery moment and intercept the reciprocal magnetic course.

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While flying the reciprocal course the pilot should look at time on the stopwatch when about L.M and follow to the inwind turn. After 2 min. he executes the second left turn with 30° bank.

As soon as the landing course is intercepted, he lowers the landing gears, reduces speed to 45 km/hr and proceeds to L.M.

The landing course interception procedure as well as the procedure followed in descent while flying the landing course to L.M and after passing the latter remain the same as in case of the straight-in approach.

IV Approach Procedure

IV landing course interception procedure is used in case of aircraft radio compass or IIM or L.M failure.

By intercepting radio bearings, the pilot brings the aircraft to IV at a specified altitude. At the moment of IV passing (when the ATC officer gives signal [illegible]), he looks the time, intercepts the course indicated by the ATC officer and continues to fly this course during estimated time.

While following the straight-in approach procedure the pilot will periodically request radio bearing and check the course. After the estimated time has expired, he performs a turn to intercept the landing course. At the last quarter of the turn he requests radio bearing again and finalizes interception of the landing course by changing the bank. In the process of descending he will request radio bearing two or three times more and will introduce correction to the landing, if necessary.

The conditions of descent while flying the landing course remain the same as in the case of the [illegible] instrument landing facility approach procedure. The diagram of distribution of pilot's attention will also be the same.

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When on the landing course the pilot has to pass [illegible] (i. the latter is located at [illegible]). When the [illegible] signals [illegible], the pilot sends the aircraft into descent, finalizes his judgement and executes landing.

Radar Controlled Approach Performed from Rated Positions

For the [illegible]-21[illegible]-1[illegible] aircraft the rated position approach for landing constitutes the basic approach procedure particularly in those cases when the aircraft returns from an interception mission or performs maximum range flight. If this procedure is used the tactical radius of action of the aircraft essentially increases as the aircraft does not waste time to fly to an airfield navigation facility and plan the maneuver for straight-in approach.

Downward cloud penetration is started at the airfield approaches without preliminary flying to an airfield radio beacon.

Rated position approach for landing is carried out as follows. While flying to the airfield the pilot establishes radio contact with the tower, reports his flight altitude position and on reaching the rated for this altitude position after being instructed by the tower sends the aircraft into descent at a rated condition and in a specified direction (Fig.52). The direction of descent (course) is selected with the aim to allow the pilot to reach 2000 m. at the point of commencement of the turn to intercept the landing course. At this stage of descent the tower follows the aircraft flight closely and corrects the heading, if necessary.

While descending to 2000 m. the pilot will establish 500 km/hr IAS and 40 m/sec. rate of descent. The rated positions of descent for this condition of descent are given in Fig.53.

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At 2[illegible] m. the pilot returns the aircraft to level flight, then by establishing 3[illegible]° bank performs a turn (coordinated turn) to intercept the landing course. To finalize interception of the landing course he should change the bank of the aircraft.

While following the landing course in 3 sec. level flight the pilot lowers the landing gears and commences descending onto L.M.

The condition of descent at this stage is similar to that used in straight-in approach procedure.

If this approach procedure is followed by a pair or a section of aircraft, the latters must in all cases use echelon orbat formation and to reach the descent commencement position must fly tangent to the latter. After the group has reached the descent commencement position, the tower instructs the pilots of the group to break off and indicates the direction for descent. By following this instruction the group leader executes a 45 - 6[illegible]° bank turn and starts to descend in the indicated direction. The following aircraft continue to fly their heading. Following tower's instructions, every next pilot, after allowing the safe time interval to elapse, performs a coordinated turn to intercept the course indicated by the tower and descends on this course to 2[illegible] m. At this altitude each pilot independently executes a 3[illegible]° bank turn to intercept the landing course, lowers the landing gears and proceeds to descend onto L.M.

In case of inaccurate alignment with the runway while making straight-in or rated position approach in low cloud ceiling weather conditions, the pilot has to follow altered approach procedure by executing twin 1[illegible]° turns below clouds at an altitude not less than 3[illegible] m. or in clouds as the case may be.

The tower and the ATC officer must have rated positions of descent for all altitudes up to the aircraft service ceiling as well as rated positions of descent from 1[illegible], [illegible] m. through

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with higher rates of descent. It is advisable to descend [illegible] 12,000 m. at 1[illegible]/sec. rate of descent. To rate the position, it is necessary to plot a point of descent from 2 [illegible] m. on the plotting pallet, with due allowance for a 30 sec. level flight square.

This point is a centre of semicircles drawn to denote aircraft turn for intercepting the landing course using 30° bank and 500 km/hr IAS. The radius of turn is found from the equation

$$R = \frac{V^2}{9.81 \operatorname{tg}\beta},$$

where, V is flying speed, m/sec.;
β - aircraft bank angle.

The rated positions for each altitude are drawn tangential to the semicircles. The tower and ATC officer must have such plotting pallets at their disposal.

Group Flying in Adverse Weather Conditions

Group flying in adverse weather conditions with employment of instrument landing systems is one of the most complex aspects of combat training and requires particular thorough planning. Only those pilots are allowed to practice group flying in adverse weather conditions who have fully qualified in individual flying in clouds with employment of instrument landing systems and have acquired firm habits in group flying in simple weather conditions.

High progressive and vertical speeds which are accompanied by considerable values of instrumental errors present a certain difficulty in maintaining given conditions used in group flying in adverse weather conditions; this factor requires more accurate and thorough ground preparation of flight personnel.

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Safe Time Interval for Cloud Penetration

Safety of flying in adverse weather conditions during successive cloud penetration upward by single aircraft and by groups of aircraft along the same estimated trajectories is ensured by maintaining estimated time interval between the aircraft at take-off, and during cloud penetration downward - by maintaining estimated time interval between the aircraft at the position of break off.

Estimation of the safe time interval t_{safe} is based on the conditions, which exclude any chance of overtaking of an aircraft (a group of aircraft) flying in front by a following aircraft.

t_{safe} is found from the equation:

$$t_{safe} = \frac{2 \cdot \Delta V}{V} \cdot t,$$

where ΔV is maximum deviation of a flying speed from a given speed, km/hr;

V - trajectory speed in climb or in descent km/hr;

t - time from the moment of take-off to the moment of reaching a given flight level or time from the moment of descent commencement to the moment of reaching L.H., sec.

When ΔV value is determined, allowance is made not only for the error committed by the pilot but also for the value of instrument (the I.A.S. and T.A.S. indicator sub-error) error which at high flying speeds of M = 1 and above may exceed the value of the error committed by the pilot. Due to this it is recommended for calculation of t_{safe} for cloud penetration upward to take ΔV = 50 km/hr for all categories of flight personnel and ΔV = 35 km/hr when climb and penetrated downward.

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Lower value in case of downward cloud penetration is explained by the fact that lower indicated air speeds in descent have lower values of instrumental errors corresponding to them.

Coefficient 2 of the equation is taken from the assumption that two aircraft flying in succession will have deviations of a flying speed from a specified one maximum in value and contrary in meaning. With this assumption as well as with the above said allowance for speed indicator error, introduction of an additional coefficient of safety into the equation for determining t_{safe} is deemed superfluous.

Table 1[illegible] gives values of t_{safe} calculated by means of the equation and rounded to acceptable for practical use values.

Table 1[illegible]

H, m.	1000	5000	10,[illegible]	1[illegible],[illegible]
t_{safe} for upward cloud penetration, sec.	1[illegible]	2[illegible]	4[illegible]	6[illegible]
t_{safe} for downward cloud penetration, sec.	2[illegible]	2[illegible]	2[illegible]	2[illegible]

Values of t_{safe} indicated in the Table for upward cloud penetration will be maintained by aircraft or groups of aircraft taking-off in succession and following the same trajectory of flight. If aircraft or groups of aircraft take-off in succession and then penetrate clouds on two different trajectories, their time interval at take-off must be equal to 1/2 t_{safe} and if they penetrate clouds on three different trajectories they will have to maintain time interval at take-off which constitutes 1/3 t_{safe}.

The Table gives t_{safe} for downward cloud penetration to be maintained between the aircraft which are broken off on a loop. When a group is broken off on the reciprocal course

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the time interval to be maintained in this case will be equal to 1/2 t_{safe}.

Upward Cloud Penetration while Flying in Pair, Pair Join-Up above Clouds, Breaking and Downward Cloud Penetration

The pair can perform upward cloud penetration as follows:

(a) in succession;

(b) by a pair flying in close formation;

(c) by a pair flying in extended line abreast combat formation.

The pair flying in succession will use the following procedure for upward cloud penetration. The aircraft take-off one by one. The wingman commences take-off roll either on the ATC officer's instruction or independently on expiration of the rated safe time interval since leader's take-off. Bringing the aircraft into a climb is performed starting from a position established for a given airfield. While climbing, the aircraft of the pair maintain the same heading and the same condition of climb. After penetrating clouds both aircraft have to reach an altitude 300 m. below a specified flight level. Each pilot will report to the tower that he has attained this altitude.

Join-up above clouds can be performed either on a loop, or overhead a NDB or on a specified course of flight by means of speed maneuvering.

While performing join-up on a loop, the leader, after being advised by the wingman that the latter has reached an altitude 300 m. below a specified flight level, gives order TAKE-OFF, and commences a turn to fly LOOP. The wingman begins an identical turn after expiration of half the safe time interval, counted off from the moment command TAKE-OFF was given.

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Join-up of the pair should take place either in the process of the turn or en route to L.H.

In case join-up is executed by speed maneuvering, the leader, after emerging from clouds and attaining a specified altitude, strictly adheres to a specified course and flying speed.

To ensure join-up the leader has to maintain, as far as possible, lower speed (not exceeding [illegible] km/hr) and the wingman develops higher speed. In detecting the leader, the wingman joins the formation according to the usual procedure.

Upward cloud penetration by a pair flying in close formation is considered to be a most expedient procedure which most amply meets the requirements consisting in speediest introduction of fighters into an engagement.

Close formation upward cloud penetration procedure is as follows.

The aircraft take off in pair. It is advisable that while entering clouds and flying in them the pair uses echelon right formation maintaining one aircraft length distance and one wing span interval, the wingman flying 3 - 5 m. lower than the leader. After being advised by the wingman that the latter is ready for cloud penetration, the leader enters clouds at specified flight condition, flies only by reference to the instruments strictly adhering to a specified condition and avoiding sharp evolutions, and issues concise commands, enabling the wingman to keep his station in the formation. While keeping his station, the wingman always follows the procedure used by the leader. He must not be deceived by possible false sensation as to the leader's aircraft attitude.

In case the leader drops out of sight or visibility in clouds deteriorates to an extent which makes impossible further penetration of clouds in close formation, the wingman immediately changes to instrument flight and at the same time executes a maneuver to extend the combat formation in order to avoid collision. This may be done by performing 15° turn with 15 - [illegible]

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[illegible] to leave the formation after which (in 1 - 1.5 min. of flying) the wingman intercepts the cloud penetration course again.

Cloud penetration by a pair flying in extended aircraft [illegible] formation is carried out in the following order. After taking-off in pair and reaching 2[illegible] m. the wingman, having checked operation of the flight and navigation instruments, makes 15° turn off the leader and reports the latter on his readiness for cloud penetration. The leader, on reaching the climb commencement position, issues a corresponding command and both pilots begin to climb simultaneously. Both maintain the same engine power setting and speed, but different course of flight.

On reaching 3 [illegible] m. the wingman turns his aircraft to intercept the leader's course and flies this course till above clouds.

Join-up of the pair above clouds is carried out by means of formation closing. Due to problematical character of this join-up, it is recommended, when this cloud penetration procedure is used, to utilize ground radar. Radar information will enable the tower navigation to expedite join-up of the pair by issuing corresponding instructions.

Downward cloud penetration can be performed by individual aircraft or by pair using close formation, subject to pilots' flight qualification, availability of navigational facilities and actual weather conditions.

In the former case prior to entering clouds for descending, the pair has to extend to maintain safe time interval between the aircraft. Procedure of extending is carried out independently or on tower's instructions.

When performing formation extension procedure independently, the pair carries out joint flight to LOM and thereafter executing a coordinated turn out at a calculated angle proceeds to break-off position. After break-off each pilot independently turns to intercept the landing course and then proceeds to descend.

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The wingman commences his turn to intercept the landing course after half the safe time interval has expired.

In case formation extending procedure is controlled by the tower, the pair will be instructed to fly straight to the break-off position to reach the predicted point for commencement of turn (coordinated turn) of the leader to intercept the landing course. Landing course interception turn angle will be different for each aircraft. The wingman turns to fly NEB after one safe time interval has expired since the leader has intercepted the landing course.

Pair close formation downward cloud penetration procedure is recommended to be used in case of wingman's aircraft flight and navigation instruments failure as well as in case radio contact is lost.

Section Upward Cloud Penetration Procedure, Join-Up of Section above Clouds, Break-Off and Downward Cloud Penetration Procedure.

To perform upward cloud penetration and join-up above clouds the section will use the same procedures and flight conditions and will follow the same sequence of actions as employed by the pair.

When clouds are penetrated upward by successive individual aircraft following the same course, take-off and cloud entry of each subsequent aircraft will be carried out after expiration of safe time interval.

The section leader will issue order for join-up after he has been advised by the formation closing wingman that the latter has reached a specified altitude. Join-up is performed either on a loop or on a specified course by speed maneuvering.

Cloud penetration can be also performed by successive pairs maintaining safe time interval between them. In this case each pair climbs in close formation in the same direction or the aircraft use two trajectories for climbing (flying in pair extended abreast combat formation).

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After penetrating clouds upward the section will join up above clouds by using the same procedure utilized for cloud penetration by pair.

Section break-off above clouds and subsequent downward cloud penetration will be performed according to the procedures recommended for the pair.

Most widely used in the procedure when the aircraft fly right and intercept a course close to reciprocal one to fly in turn position during section formation. In reaching the position of turn the section breaks-off into individual aircraft in that specified safe time interval between the aircraft be maintained on the landing course. All the aircraft begin descending from the same position.

Characteristic Errors of Pilots During Flights in Adverse Weather Conditions and Procedures Used to Correct Them

Flight technique errors, committed by a pilot during flight in adverse weather conditions, are the result of careless ground preparation for flights, improper operation of aviation equipment, commanding officer's negligence in allowing a poorly qualified pilot to fly the combat airplane or in allowing a pilot who had prolonged interruption in flights to fly the combat aircraft without first recovering lost habits by flying a trainer. It is characteristics of a poorly qualified pilot to display general tensity in flight and inability to come to a correct decision in complex situation, which can arise in flight.

Characteristic error and procedures used to correct them are discussed below.

Careless check and preparation of the flight and navigation equipment for flights prior to takeoff and prior to cloud entry. Violation of rules governing procedure of flight check of the flight and navigation instruments prior to take-off and prior to cloud entry results in the fact that

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instrument failure is not detected in due time and an aircraft embarks on a mission with its instruments being inoperative.

Negligence in respect of timely preparation of the instruments for their normal operation in flight may lead to either their failure in flight or to disorientation of the pilot.

If, while on the ground, the pilot fails to set the altimeter pointer to zero, or does not set the required course against the given course index, or fails to switch on the pitot-static tube heating and clock flying time locking button, or fails to tune the radio compass, in most cases these operations may be neglected in flight either. Due to his preoccupation in flight, he may simply forget the operations he has neglected before flight and even if he recalls them, it might already be late to rectify committed error in maintaining the specified condition of flight or restore normal operation of instruments.

Untimely transition to instrument flight during cloud entry. Instead of gradual transition from visual to instrument flight prior to entering clouds during upward or downward penetration, and thus preparing for flying in clouds, the pilot continues visual flight until after the aircraft enters the clouds and only then he switches his full attention over to the instruments. Such procedure of flying entails occurrence of illusion, augmentation of nervous tension and arouses distrust towards instrument readings.

Failure to maintain a specified climbing condition. The attempt to maintain a specified condition of climbing often entails failure to maintain a specified speed on trajectory. This may be due to the fact that either the pilot underestimates the role, accurate maintenance of flying speed in climb is playing in safety of flying and successfull execution of the mission, or he is poorly trained in distribution of his attention as well as in reacting fast and efficiently to all possible deviations from a specified speed.

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Premature transition from instrument to visual flight after breaking clouds. The error is manifested in the fact that the pilot exhibits unnecessary haste for transition from instrument to visual flight. At the end of cloud penetration the clouds usually become brighter and in case of upward cloud penetration the pilot may often catch a glimpse of the sun. This phenomenon may create false impression that the aircraft has already emerged from the clouds, and therefore the pilot leaves the instruments and will tend to switch over to visual flight.

However, the cloud edge often proves to be dissolved, the clouds turn into dense once and the pilot will be compelled to change over to instrument flight again.

Inaccuracy in attaining the descent commencement point. Inaccuracy in maintaining a given position and time for transition to descent is affected by:

(a) delay in execution of a coordinated turn at a specified calculated angle;

(b) failure to maintain flying speed and the estimated time to fly from L.H to the point for commencement of the turn to intercept the landing course (the pilot usually increases this time period);

(c) no or wrong allowance for wind is made during determination of $t_{lev.fl}$ value and of estimated angle;

(d) inaccurate interception of the landing course after turn recovery;

(e) aircraft transition to descent immediately after execution of the turn to intercept the landing course (without performing 30 sec. level flight).

Inaccuracy in maintaining a specified condition of descent. The most characteristic errors during descent are as follows:

(a) failure to maintain specified values of progressive or vertical speeds;

(b) failure to maintain the landing course.

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Effect of errors, committed during descent, on accuracy in reaching cloud ceiling position relative to LOM may prove to be not less than effect on errors committed by the pilot during execution of a maneuver above clouds. Therefore, the pilot has to pay constant and close attention to maintaining a specified condition of flight at all stages of approach.

Failure to maintain the landing course is explained mainly by disregard for side wind effect.

Premature transition to visual flight while proceeding to LOM below clouds. This error is usually manifested in the fact that the pilot, after reaching minimum safe altitude particularly when breaking through clouds at a point far from LOM, searches for familiar check points and airfield; distracts his attention from the instruments, loses altitude control and allows the aircraft to descend to altitudes which may lead to crash against an obstacle or the ground.

Errors during execution of group flying in adverse weather conditions may be due to failure to maintain safe time intervals between the aircraft during climb and descent, due to failure to maintain required conditions for reliable join-up of the group above clouds, due to failure to maintain non-expedient intervals and distances between aircraft during cloud penetration in close formation.

Failure to maintain safe time intervals in flight is the result of non-adherence to specified conditions of flight and failure to maintain corresponding time intervals at take-off.

In case of group flying, failure to maintain a specified condition after break-off for landing may result not only in aircraft breaking through clouds at a point unsafely far from LOM which may enhance chances to crash against an obstacle or the ground, but also in dangerous reduction of distances between the aircraft which may lead to collisions in clouds.

If the pilot does not follow the procedure of aircraft dispersal above clouds after take-off, the procedure of turns

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and other specified maneuvers in and above clouds, join-up of the group may be delayed or will not take place at all.

High circumspection when looking out for the leader above clouds and high accuracy in maintaining a specified condition of flying by all pilots are of great importance for insuring reliability of group join-up.

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Chapter VII

NIGHT FLYING

Night flying on the [illegible]-21 -13 aircraft possesses a number of certain features, which distinguish it from daytime flying.

Great number of instruments, special equipment and levers, controlling various assemblies, installed in the cockpit demands that the pilot, engaged in night flying, should know firmly the layout of the flight instruments, the existing procedure to operate the assemblies and all equipment of the cockpit and be able to follow properly the procedure of transition from instrument to visual flight and vice versa.

The flight personnel, qualified for night flying on the МиГ-21Ф-13 aircraft must be perfectly acquainted with the aircraft lighting equipment and with the procedure of its operation on the ground and in flight. With this aim in view the main attention during preparation for flights will be concentrated on training in the cockpit proper.

This training must be conducted only at night.

In the process of cockpit training the whole flight is rehearsed by stages, from take-off to landing; the rehearsal includes the procedures used by the pilot at these stages.

During the cockpit training the instructing pilot will coach the trainee in practising engine starting, emergency procedures and handling the equipment installed in the cockpit, taking particular care in developing pilot's habits to grope for any switch, push-button or lever.

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What are the distinguishing features of cockpit equipment handling which demand pilot's attention during preparation for night flying?

First of all, in contradistinction to the preceding types of aircraft, the MiG-219-1[illegible] aircraft is to be taxied with the nose wheel turn mechanism being on and the nose wheel brake mechanism being off. The latter is turned on immediately before take-off.

When speed is high enough on landing run the pilot should reset the brake chute and jettison it after termination of landing run.

The chute ejection push-button is poorly visible at night. And as the rocket and ventral tank emergency drop push-buttons are located also on the instrument panel, the pilot, in case he has vague idea of the chute ejection push-button location, may confuse the buttons and push other button than required. Therefore, in the process of cockpit training pilot's attention must be repeatedly drawn to the fact that chute ejection button is located to the left of G-load indicator, against figure 4 which is clearly visible at night. Besides, the pilot may be recommended to grope for the chute ejection button. If the pilot moves his hand down along the left edge of the instrument panel, this button will come under his thumb.

The chute jettison push-button can also be found by groping, but pilot must remember that it is located somewhat above the flap control buttons.

Proper raising of the nose wheel as well as correct landing path depend largely on vertical adjustment of the seat.

Arrangement of the cockpit offers good observation though the pilot must take care in adjusting the seat to his height.

Experience of flying proves that quite often the pilot, instead of turning on the taxi light, switches the automatic radio compass from LGM to LIM. These switches are located near to each other. The pilot must acquire particularly firm habits in their handling as this factor may largely affect success

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and safety of flight. It must be remembered that landing light switch is located above the NW arm indicator, and the automatic radio compass selector switch is installed below the chute ejection button, near the wall, and can be found by groping the same way as the latter.

During cockpit training it is necessary to memorize location of all other equipment installed in the cockpit and the pilot should elaborate a certain procedure he will follow to find undoubtedly any instrument without turning on cockpit lighting. Before flight the navigation light switch is usually set in position 3 PER CENT. This brightness of the lights will amply provide for flight safety. In case of visibility deterioration, however, or due to other reasons the pilot may be instructed to set 100 per cent for the navigation lights. The navigation light subpanel is not illuminated and the figures are not visible. The pilot should commit it to memory that the fore and down position of the switch corresponds to 100 per cent brightness of the lights and that the switch is located below the chute jettison button.

Prior to taxiing all lights and light panels will be set in positions for night flying. The FLAPS DOWN light illuminates brightly, when the flaps are lowered for landing, and, being in sight, distracts pilot's attention and becomes a nuisance for landing.

This light has no blind, therefore, prior to night flying its bulb must be covered with easily removable paint.

The cockpit is not provided with an anti-shine blind. Therefore, intensive shines in the form of three iridescent strips appear on front upper part of the cockpit glass. They make instrument flying more difficult and deteriorate visibility from the cockpit. Due to this, the pilot, executing night flying, must be always on lookout particularly during approach to avoid aircraft closing on each other.

Limited quantity of fuel carried by the aircraft, demands that the pilot should maintain continuous watch for its consu

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don in flight particularly when the engine is operating with afterburner on. At night, only those figures of the fuel flow indicator are visible which denote thousands of litres, while the intermediate points are concealed by darkness. To determine quantity of unused fuel the pilot will occasionally light the fuel flow indicator dial by an extension white lamp.

When the engine operates at afterburning power setting, the pilot will have in sight light blue somewhat wavering background and a luminous train behind the aircraft tail will come in pilot's view during a turn.

The blue background becomes more intensive in clouds. These signs assist the pilot to determine whether the afterburner has switched on and whether the aircraft has entered or has emerged from clouds. It must be remembered that at the moment of cutting the afterburner in and particularly at the moment of cutting it off the pilot must change over to instrument flight and then gradually return to visual flying.

In case of the MiG-21-15 aircraft, the navigation lights are visible from the cockpit. This arrangement minimizes the chance of take-off with the navigation lights off and enables the pilot to detect lights failure in flight. In all cases of navigation light failure the pilot has to switch on the taxi light, keeping it in mind that the latter's switch is located nearby the automatic radio compass selector switch.

After the pilot perfectly familiarizes himself with the cockpit in the course of cockpit training and displays full confidence in handling the aircraft equipment, he may be allowed to proceed to solo flying.

The pilot who is allowed to perform his first solo flight on the MiG-21-15 aircraft will be advised to execute the circuit flight before darkness on the same aircraft he is expected to fly at night.

This flight must be carried out [illegible] the flight, the pilot should [illegible] from the nose wheel is [illegible] at the moment of unstick.

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Planning of the first night flight must stipulate for good visibility of the natural horizon and possibly not dark night.

Pre-Flight Preparation

On entering the cockpit with external power on the pilot, apart from performing operations required for daytime flying, must set the navigation lights to the 3-PIR CENT position which ensures good observation of the aircraft on the ground and in flight and at the same time presents no encumbrance for the pilot. After illuminating the cockpit with a white light lamp the pilot proceeds with the following:

(a) while checking the aircraft lighting equipment he closes the LANDING LIGHTS, LANDING GEAR EXTERNAL INDICATOR LIGHT (ФАРЫ, СИГНАЛИЗАЦИЯ ШАССИ) circuit breaker installed on the front starboard electrical subpanel;

(b) closes the GENERATOR SIGNAL OIL PRESSURE [illegible], [illegible] (СИГНАЛИЗАЦИЯ ГЕНЕРАТОРА, ДУП, КИС, [illegible]) circuit breaker, installed on the port electrical subpanel;

(c) with the help of the РУЛ-45 rheostat illuminates the ultra-violet lights, adjusts light filters and sets light fittings in operating positions; the ultra-violet lights located on the control stick and cockpit wall provide for sufficient illumination of the instrument panel;

(d) sets the landing light switch to the TAXIING LIGHT (РУЛЕЖНАЯ) position and makes sure that the taxi light is operative and properly adjusted, then turns the switch to the LANDING LIGHTS (ПОСАДОЧНАЯ) position and checks operation of the landing light and direction of the light beam; after the checks, he returns the switch to the OFF position;

(e) closes the SIGHT HEATING (ОБОГРЕВ ПРИЦЕЛА), SIGHT (ПРИЦЕЛ) circuit breaker, installed on the front starboard electrical subpanel, adjusts required brightness of the sight grid and then opens the circuit breaker;

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(f) sets the blinds of the signal lights at both light panels and flight and landing signal unit to night flight position;

(g) adjusts the blinds of the signal lights: DROP TANK SIGNAL LIGHT (СИГНАЛЬНАЯ ЛАМПА ПОДВЕСНОГО БАКА), ЗАП ZERO POSITION (ЗАПУСК ПОЛОЖЕНИЕ НУЛЬ);

Note: Prior to entering the cockpit it is necessary to make sure, that all circuit breakers required in flight, which are located on the rear starboard electrical subpanel, are closed.

(h) requests clearance for engine starting; after starting and test running the engine he switches off the white light lamp and requests clearance for taxiing.

Circuit Flying

Taxiing

After being cleared to taxi, the pilot applies brakes, blinks the navigation lights giving the ground engineer a signal to remove wheel chocks, extends the taxi light, and after making sure that the chocks are off and the way is clear, starts taxiing to the runway.

The taxi light installed on the [illegible] -15 aircraft poorly illuminates the ground in front during taxiing. Therefore, depending on visibility conditions the pilot will periodically turn the landing light on during taxiing.

Taxiing will be performed at a speed not exceeding 15 - 30 km/hr. Taxiing procedure at night does not differ from that in the daytime.

On approaching the runway the pilot should look around, making sure that the runway is clear and no aircraft is landing, and request clearance to enter the runway.

After entering the runway the pilot rolls the aircraft 20 - 50 m. forward to align it with the runway centre line and

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parallel to the runway lights and then, after performing all pre-take-off operations required, requests clearance to take off.

Take-Off

After being cleared to take off, the pilot applies brakes, increases r.p.m. to maximum ones, releases the brakes and begins take-off roll.

During take-off roll the pilot must look straight forward through the armoured glass to keep the runway lights line in sight. He will use the runway lights for directional control.

As airspeed builds up to 200 km/hr the pilot applies smoothly back stick pressure and raises the nose wheel off the runway to the required position. If the horizon is visible, the pilot will use both the horizon and runway lights to control the aircraft nose position; if the horizon is not visible, the latter will be controlled by the runway lights only.

In the process of take-off roll the aircraft nose must be raised to the same position as during daytime take-off. If during take-off the nose wheel is not raised sufficiently, take-off roll enhances considerably, the aircraft unsticks only at the end of the runway and the pilot is unable to check the aircraft attitude after unstick by the exit and take-off lights, as he hits darkness immediately after unstick.

At the moment of being airborne, the pilot, without changing the position of the controls, shifts his eyes to the left side of the runway lights and continues climbing gradually flying off the ground.

After unstick the MiG-21D-13 aircraft tends to assume high angles of attack and if the control stick is kept in the position it had moved to at the moment of unstick, the aircraft will climb with insignificant growth of speed. It may not be unsafe in the daytime, as having the ground in sight the pilot

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move the stick forward and impart a normal angle of climb the aircraft.

This procedure is not to be used at night, particularly the cases when unstick has been accomplished at the end of runway and the pilot has no chance to determine altitude visually.

Brisk advancement of the stick may lead to abrupt descent the aircraft. Therefore, after the aircraft has flown off runway the pilot is advised to keep the stick in the same position, at first, and then, with speed growth, to move it gradually forward, preventing, though, the aircraft from dropping its nose below the horizon and from descending. Aircraft behaviour after unstick depends largely on the trimming effect mechanism position, therefore, before take-off the pilot must be sure that the trim tab is neutral.

At 15 - 2. m. the pilot retracts the landing gears. After runway lights have been passed, the aircraft attitude in climb will be controlled by the natural horizon in conjunction with the artificial horizon, rate of climb indicator and speed indicator. When taking-off in pitch darkness, the pilot performs climbing and controls the aircraft attitude by using only the artificial horizon, rate of climb and speed indicator.

On reaching 150 m. the pilot retracts the flaps and continues climbing maintaining 500 km/hr speed and 8 - 10 m/sec. rate of climb.

Flight Planning

After attaining 200 - 250 m. the pilot looks around paying particular attention to the direction of the turn, and performs crosswind and downwind turns as a single uninterrupted procedure establishing 30° bank and continuing to climb.

In the second half of the turn he consults the compass from time to time and plans turn recovery to intercept the reciprocal course.

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Traffic pattern altitude is attained on the reciprocal course.

Fig.54 displays the diagram of circuit flying at night.

While flying the MiG-21-15 aircraft at night the pilot must pay more attention to maintaining a given flight condition (speed, altitude and bank). It implies that he has to give more of his mind to instrument flying of the aircraft.

After accomplishing two circuit flights at a specified altitude, the pilot, if cleared by the ATC officer, descends to 500 m. at a given point and joins short-leg traffic pattern at 500 km/hr speed.

When abeam the landing Tee and at a speed of 500 km/hr, he lowers the landing gears, checks whether they are down and locked and requests clearance for landing.

The same procedure, as in daytime flight, is used to check landing gear extension. The landing gear down position external signal lights are not visible from the cockpit, but when they illuminate, they irradiate a greenish colour which can be used to determine, whether the landing gears are down, in case of the MMC-2 signal light system failure.

The downwind leg will be somewhat longer at night than during daytime flying in order to avoid a bank exceeding 45° during base leg turn.

To check the turn commencement point the pilot is advised to use the automatic radio compass readings. The base leg turn will be entered when DPM relative bearing is equal to 260 - 265°.

The base leg turn will be a 100 - 110° turn performed at 500 km/hr with 30° bank. Bank recovery is accomplished according to the compass and automatic radio compass readings.

When executing turns at night, it becomes a problem to determine aircraft bank value. The latter always seems to be shallower than it really is. If banks are shallow (up to 30°) the aircraft is sluggish in turning and the pilot tends to increase the bank. This explains the fact that pilots, when

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executing base leg and final turns, establish turns up to 60° and higher. The pilot must always keep in mind this peculiarity of the aircraft and in the process of turns, when the latters are performed at a low altitude, in particular, should check the bank by consulting the artificial horizon and turn-and-bank indicator.

After turn recovery the pilot lowers the flaps, sets gliding speed to 45 km/hr, relieves stick forces by using stabilizer "trimming effect" and checks the [illegible] position (the STABILIZER FOR LANDING inscription must illuminate on the [illegible]-4 light panel).

When the angle between the line of the runway lights and that of the landing Tee extension is 2[illegible] - 25° and at 4[illegible] - 5[illegible] m. the pilot commences the final turn maintaining a speed not lower than 42[illegible] km/hr and establishing a bank not exceeding 45°.

At the initial period of night flight training, the pilot is advised to start final turn somewhat earlier, so that he may use bank value decrease rather than increase, when finalizing the judgement by means of the runway lights.

He must plan to recover from the final turn at an altitude not less than 3[illegible] m.

After turning final, even though his judgement is accurate, the pilot gets an impression of overshoot.

For the [illegible]-21 -1[illegible] aircraft the L[illegible]-to-LIM flight time and the LIM-to-flare-out point flight time will be 28 and 1[illegible] sec. respectively.

Reduction of flying time at these sections of descent will highly complicate judgement and will require very efficient handling of the controls and the engine on the part of the pilot.

Having recovered from the turn, the pilot establishes a glide angle to descend into the first (for approach) [illegible] light beam which will represent the flare-out commencement

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point and takes care that glide speed diminishes gradually to attain 340 - 350 km/hr at the point of flare-out.

The pilot will check glide path by using a code neon light beacon located near to LIK or LIM proper which have to be passed at an altitude not less than 100 m.

While gliding on final he must take special care to maintain a speed not lower than 340 - 350 km/hr.

In case speed drops rapidly, on gliding, the pilot has to increase engine r.p.m. briskly without allowing the speed to drop to 340 - 350 km/hr, otherwise the speed may decrease below 340 - 350 km/hr and the aircraft will start to lose its altitude fast. This moment may be passed unnoticed by the pilot, while due to aircraft sluggishness and insufficient accelerating ability of the engine, subsequent rectification of the error by back stick pressure will be accompanied by further loss of altitude and may lead to the aircraft roughly touching down the runway portion not illuminated by searchlights.

Landing

When on final and gliding to 50 - 80 m., the pilot is occupied mainly with finalizing accuracy of approach and judgement and with checking aircraft speed.

At 30 - 20 m. the pilot shifts his eyes to the flare-out commencement point and concentrates all his attention on flight altitude.

On reaching the zone lighted by the first approach floodlight, and at 8 - 10 m. and 340 - 350 km/hr gliding speed, the pilot starts flare-out by applying back pressure to the stick planning to bring the aircraft 1 m. off the runway.

In contradistinction to daytime landing during night landing the pilot will begin to retard the engine control lever after the aircraft has accomplished flare-out in the lit zone and is already 1 m. above the runway. At the moment of touchdown the control stick will be kept in the position it reached before touchdown.

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After steady 15 - 2 m. roll the pilot lowers the nose wheel smoothly and turns his eyes to look straight through the windscreen glass, then he begins to use brakes gently and at a speed not exceeding 280 km/hr ejects the brake chute.

The pilot maintains directional control by keeping the runway lights in sight. The procedure of brake application is similar to that used during daytime landing. After terminating landing roll, the pilot raises the flaps, turns off the nose wheel brake and switches on the taxi light.

The brake chute is jettisoned after the aircraft has cleared the runway. The aircraft proceeds to the parking place with the taxi light on. The landing light will be also used if and when necessary.

Night go-around procedure is similar to normal daytime go-around procedure, except that the former requires higher attention on the part of the pilot.

Procedure of using the landing light while landing on a runway unlit by floodlights. Night landing with application of the landing light while landing on a runway unlit by floodlights presents a certain problem and demands that the pilot pay higher attention to determining altitude of flare-out and floating.

After turning onto final approach the pilot selects angle of glide planning to descend to the flare-out commencement point which coincides with the runway threshold lights.

At an altitude not lower than 1 m. he switches on the landing light by turning the selector switch to the LANDING LIGHT (ПОСАДОЧНАЯ) position.

Gliding speed is maintained at 3 - 350 km/hr level up to the end of flare-out by selection of engine r.p.m. equal to 6 - 7 per cent.

At 3 - 2 m. the pilot turns his eyes to the ground lit by the landing light and concentrates all his attention on determination of flare-out commencement altitude.

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At 10 - 12 m. the pilot starts flaring-out by applying back pressure to the stick and plans to bring the aircraft 1 m. off the runway. Keeping always his eyes on the ground lit by the landing light he maintains directional control with the help of the runway lights. With altitude decrease, engine r.p.m. are smoothly reduced and continuous back stick pressure is planned so that the aircraft touches the runway with the main wheels first. At the end of the landing roll the pilot switches the landing light off and turns on the taxi light.

Sector Flying

High speeds used by the MiG-21F-13 aircraft during execution of aerobatics with shallow banks considerably enhanced radius and duration of various maneuvers performed in the sector. This factor demands that the pilot should be more intent on keeping his specified position in the sector; therefore he must look out after accomplishment of each maneuver and determine his exact position by using well lit check points, runway lights and NDB.

In semi-darkness when the horizon is visible enough the pilot will use the latter to fly the aircraft and will periodically resort to the instruments to check the flight condition.

If the horizon is not visible, he will stick to instrument flying.

While executing vertical maneuvers the pilot selects maneuver entry direction planning maneuver recovery in the direction of semi-dark horizon or of a light check point visible enough.

Turns, performed for training purposes, are to be executed at 6000 - 12,000 m. and at 700 km/hr IAS with 45° bank. Prior to entering a maneuver the pilot scans the space, specifies his position in the sector, selects maneuver entry and recovery directions and sets a required speed. Execution of the maneuver is checked by means of the flight and navigation instruments.

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Zooms are entered at 900 - 1[illegible] km/hr IAS and with an angle of climb up to 30°. The aircraft will be accelerated at normal rated r.p.m. As soon as a specified speed is reached the pilot applies back pressure to the stick and establishes a required angle of climb. He will use the artificial horizon and rate of climb indicator to verify angle value and to check the aircraft for banks.

Zoom recovery speed must not be less than 500 km/hr. After this speed is reached the pilot, by coordinated movements of the controls, sends the aircraft into a turn and at the same time decreases the angle of climb planning to return to level flight at a speed not lower than 450 km/hr.

Zoom recovery at night will be performed in the direction of semi-dark horizon or of a visible enough light check point. While executing zoom the pilot has to take special care to maintain an established angle of climb to avoid banks, as well as to maintain specified speed and bank during zoom recovery turn.

Night diving will be performed at angles not exceeding 30°, both with and without application of the air brakes and at dive entry speeds of 4[illegible] - 6[illegible] km/hr IAS. After a required altitude has been lost or a specified speed attained the pilot applies back stick pressure gently to return the aircraft to level flight at a safe altitude.

Aircraft attitude in diving will be checked by means of the artificial horizon, rate of climb indicator, altimeter and electrical turn indicator in conjunction with the speed indicator.

Spiral will be performed at 500 - 550 km/hr with a bank up to 45°. Spiral single turn altitude loss will be 150[illegible] - 2[illegible]00 m. While executing spiral at night the pilot has to pay particular attention to maintaining specified speed and bank. Execution of the maneuver is checked with the help of the instruments and light check points.

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Chapter VIII

AIR NAVIGATION

Navigation ability of a pilot is one of the important elements which determine the degree of his combat trim perfection. Navigational qualification of a fighter pilot greatly influences execution of a combat mission. Therefore, a fighter pilot must be perfectly conversant with all methods presently used for fighter navigation and employ them properly in any navigational condition.

Navigation training consists of two parts: theoretical training and practical navigation. Theoretical schooling is conceived for imparting principles of navigation, methods of navigation, knowledge of aircraft navigation equipment and of ground navigational aids to the flight personnel.

The purpose of practical navigation consists in developing certain habits of the pilots which provide for accurate and safe execution of flights. The habits are acquired and perfected both on the ground while using special training equipment and in flight while piloting trainer and combat aircraft.

Navigation is closely related to aircraft piloting and its success largely depends on the quality of piloting. Pilot's ability to maintain a specified condition of flight (heading, altitude), to climb or to glide at an established vertical speed, and to execute a turn for a given angle and with a specified radius is a sine qua non for accurate navigation.

While on a combat mission, a pilot, poorly qualified in navigation pays too much attention to aircraft positioning to the detriment of circumspection and target search.

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Comparatively small amount of fuel on board and a great number of maneuvers performed at high speed require pilots very accurate navigation as to position, finding and timing.

To ensure successful accomplishment of a mission and to relieve the pilot partly of his preoccupations, the navigation procedures, mostly a fighter pilot, should be supplemented, whenever possible, by tower's instructions pertaining to aircraft position, airfield or specified point, inland herding of air or ground target interception levels.

Navigation of fighter aircraft is to be applied with the help of various technical aids (RB's, RI, radars, etc.) in combination with visual observation. Therefore, a fighter pilot must acquire and develop habits in doing several activities while carrying out night deal rocketing.

Distinguishing Features of Stratospheric Navigation

Distinguishing features of stratospheric navigation are related to:

(a) deterioration of visual observation conditions;
(b) deterioration of aircraft maneuverability;
(c) necessity to make allowance for winds of great velocity;
(d) necessity to maintain variable conditions of flight (comparatively big portions of flight are carried out at climbing and descending conditions with considerable variations of TAS at different stages of flight).

Visual observation in stratosphere presents a problem. In a flight performed at altitudes exceeding 11,000 m., problems usually above medium and top layers and in most cases under conditions of poor horizontal visibility due to bad weather. Even in fair weather cloudy weather it is difficult to identify small and large, though indistinctive, check

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points as considerable portion of the terrain is hidden under the aircraft fuselage. If at 10,000 m. the width of the hidden terrain is 1.5-2 km., at 15,000 m. it will amount to 22 - 30 km. While flying at these altitudes the pilot may fail to detect wide area check points of 20 km. and more if he does not bank the aircraft to both sides from time to time to scan the terrain lying on the aircraft track or in the direction of an expected check point.

Accuracy of aircraft position finding by means of visual observation, especially when the pilot wears the PK-7 pressurized helmet is very low, as check point angle of view is small. Such check points as railways, small populated areas, natural soil roads, shallow rivers are visible very poorly. Haze often deteriorates visibility of check points so much that the latters can be seen only when they are at small angles or direct under the aircraft.

In the morning and in the evening lower layers of the air when looked upon from 13,000 m. and above seem to be darkening and assuming reddish tint and do not allow to scan the terrain.

If the lower layer exceeds 5-7 octas, visual observation becomes absolutely impossible, as it will be a problem to observe the terrain through cloud gaps from altitudes above 12,000 m. and use it for aircraft position finding.

Stratospheric flight is carried out at high angles of attack and the terrain in front of the aircraft is hidden by the latter's nose part. So to detect a check point which is in front and along aircraft axis, the pilot will have to turn the aircraft by 20-30^0 and to establish a corresponding bank.

Visual observation is even more complicated at that portion of the flying route where the aircraft assumes climbing attitude, as high angles of pitch prevent the pilot from seeing check points lying in front of the aircraft. Visual observation is greatly affected when the aircraft climbs at afterburning power setting.

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Required accuracy of navigation in stratosphere will only be ensured if the pilot uses radio navigation aids in combination with visual observation.

During stratospheric flights, especially when they are performed at aircraft ceiling altitudes, flying technique becomes more complicated due to deterioration of longitudinal and lateral controllability and due to diminution of maximum permissible bank values. The latter factor as well as high speeds of flight in stratosphere lead to great radii of turns. Engine operation conditions deteriorate also and this induces the pilot to be more attentive in checking engine operation. All these factors divert pilot's attention from visual observation.

In addition, stratospheric flight observation is also complicated by more difficult physiological conditions of pilot's work (rarefied atmosphere in the cockpit, necessity to wear high altitude pressure suit and pressurized helmet, etc.).

With altitude increase wind velocity grows continuously reaching its maximum value at 11,000-13,000 m. (in troposphere). Maximum velocity of the wind at these altitudes may amount to 200 - 300 km/hr and above.

Such winds, even at high flying speeds, may cause angles of drift equal to 10° - 15° which can entail considerable deviations from a required track.

The above mentioned features of stratospheric navigation require combined utilization of navigational aids, induce the pilot to adhere strictly to the estimated (or specified by the tower) condition of flight and demand thorough pre-flight preparation.

In the course of pre-flight preparation the pilot will plot flight route via characteristic check points which are well visible from flight altitude; he must get thoroughly acquainted with route strip, the width of which should be not less than 150 km.

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Flight estimates are based on pilot-taken-reported or predicted winds for air speeds corresponding to certain condition and altitude of flight (for instance, the first section of the route - climbing condition of flight; the second section of the route - level flight condition; the third section of the route - descending condition).

NDB or VDF will be chosen as initial point of the route and terminal point of the route. The first reference point is selected in the climb termination zone.

In the course of pre-flight preparation the pilot must get conversant with the system of large linear and area check points within the route strip of not less than 150 km. in width, location and operation data of navigational aids and communication stations, speeds of climbing, level flight and descent and observation recovery procedures. Besides, before flight he should analyse meteorological conditions thoroughly.

When flying above clouds, a turn for intercepting a new required track will be executed according to precalculated relative bearing of radio station (bearing of DF). Prior to entering route terminal NDB (LOM of airfield of landing) operation zone, the pilot flies the compass following the estimated heading, but when the aircraft begins descending, he changes over to the automatic radio compass homing to the radio station, periodically requesting DF fixes and checking his heading by the compass.

Air Surveillance and Homing Radar Navigation Procedures

In adverse navigation conditions, i.e., when flight is carried out in clouds, above clouds and in stratosphere in the daytime and at night the pilot can use radars for navigational purposes.

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Radars can be used for homing the aircraft on a reference check point, or surface target and airfield of landing, on required track as well as for checking flight direction and speed with precision sufficient for practical navigation. For these purposes the route is plotted in accordance with radar operation range. Initial point of the route is selected off radar "cone".

The flight is controlled by the control tower navigator (operating navigator) with the help of a homing plotter or radar PPI.

The control tower navigator plots the aircraft route on the plotter or radar PPI protective glass. After aircraft detection the control tower navigator sets a course to the pilot planning to home the latter on the initial point of the route "on-course". He advises the pilot when the latter reaches the initial point of the route.

If the aircraft deviates from a required track, the navigator determines side deviation by means of the plotter or radar PPI and introduces correction into the course planning to return the aircraft to the required track, when the pilot intercepts the required track, he is given a course with allowance for drift angle.

One of the above mentioned procedures is used to home the aircraft on the next route turning point and to the required track of the next section of the route. Similar procedure will be followed when the aircraft is homed on the airfield of landing. The control tower navigator issues his instructions to the pilot via radio telephony.

When the pilot plans to use radar navigation procedure, he is to get thoroughly acquainted with the visibility zone characteristics of a given radar and procedures of cooperation with the control tower operators.

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In emergencies, i.e., when the aircraft is lost or when it is out of the radar visibility bounds, or in case of radio interference, the pilot may use radar identification system for navigational purposes. The procedure of navigation in this case remains similar to that described above.

The coded DISTRESS signal will initiate procedures to identify an aircraft on radar PPI.

The aircraft equipment makes it possible to carry out:

(a) tracking toward a radio station;

(b) homing on a radio station;

(c) flight from a radio station in a given direction;

(d) interception of a required track.

Interception of Required Track and Tracking

Inbound

When tracking inbound the pilot selects radio station magnetic bearing on the course-setter and flies the aircraft matching the pointers of the radio compass and course-setter, which under no crosswind conditions must rest against the upper triangular index of the external dial. If the aircraft leaves a required track, the pointers of the radio compass and course-setter will diverge; besides, the course-setter will deviate from the upper triangular index.

To counteract the deviation and to intercept the required track again, the pilot has to make a corrective turn in the direction of the radio compass pointer deflection allowing the latter to deflect in the direction opposite to the former deflection; then the aircraft will fly the course which crosses the required track.

While the aircraft approaches the required track, the radio compass pointer will travel towards the course-setter pointer and then will fully align with the latter at the moment

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the aircraft enters the required track. The latter will be correctly intercepted if the pilot enters the turn before reaching the required track i.e., prior to alignment of the radio compass pointer and course-setter.

Turn entry commencement moment will be determined by an angle formed by the radio compass pointer and the course-setter. The value of this angle will depend upon the distance to the radio station and aircraft maneuverability.

The rate at which the radio compass pointer approaches the course-setter and the latter approaches the upper triangular index of the external dial will indicate whether the required track interception turn is properly executed.

If the turn is executed properly the moment of the radio compass pointer alignment with the course-setter will coincide with the moment when the course-setter comes to rest against the upper triangular index. If the pilot, however, commits an error while entering the turn, he can correct it by changing aircraft bank during the turn.

If in the process of the turn the course-setter approaches the upper triangular index faster than it approaches the radio compass pointer, this will indicate that the turn recovery moment will occur earlier than the aircraft intercepts the required track (this is the case of undershoot). In this case the aircraft bank during the turn must be decreased.

In case the course-setter approaches the upper triangular index slower than it approaches the radio compass pointer the bank should be enhanced, otherwise the aircraft will pass the required track, and turn recovery will be encountered with overshooting.

When tracking inbound procedure is used, alignment of the pointer with the upper triangular index will be possible under the crosswind conditions. In case of crosswind the aircraft must be turned through a drift angle. Thus, in case of drift the converged pointers of the radio compass and course-setter

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will rest against one of the graduation marks of the upper section of the dial, reading an angle equal to the aircraft drift angle.

Homing on a radio station with the help of the KGM gyro induction compass does not differ from that executed with the help of the APK-5 radio compass.

Tracking Outbound

When tracking outbound, the difference in the KGM gyro induction compass indications will consist only in that the opposite end of the radio compass pointer aligns with the course setter pointer.

Approach of the aircraft to the required track is indicated by the position of the upper triangular index on that half of the dial (relatively to the course-setter) to which the radio compass pointer is directed.

For tracking outbound in a given direction it is necessary

(a) to hold on-course when the pointers of the radio compass and course-setter are matched;

(b) if the pointers of the radio compass and course-setter diverge, to bring them in line by introduction of a correction into the heading so that the upper stationary index points to that half of the dial (relatively to the course-setter) to which the radio-compass pointer is directed.

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Chapter IX

EMERGENCY PROCEDURES

All around proficiency of the pilot to meet any urgencies or emergencies in flight plays a decisive role in adoption of proper measures to provide for safety of flying.

In case of any emergency which requires assistance or rescue procedures the pilot must send a distress signal through the identification system.

In all cases of aircraft equipment failure the pilot has to advise the ATC officer on the nature of failure and then to follow the procedures, required by the situation, and the instructions of the ATC officer.

Procedure on Engine Cut-off in Flight

In case of engine cut-off the pilot is to proceed as follows:

(a) to move the engine control lever aft to the CUT-OFF position immediately;

(b) to advise the tower on engine failure;

(c) to descend to 12,000 m. (descending will be performed in the direction of the home or nearest airfield) and to restart the engine.

The engine provided with oxygen feed for restarting at the chamber igniters is reliable in starting at 12,000 m. and below. The low-pressure rotor autorotation r.p.m. are 20 - 30 [illegible] ment.

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These autorotation r.p.m. ensure IAS of 450 - 650 km/hr.

The oxygen feed system provides for five startings; duration of one starting must not exceed 30 sec.

CAUTION. If oxygen is not available in the oxygen feed system or in case the latter is malfunctioning (pressure gauge indicates pressure drop to 0) the engine will be started at altitudes not higher than 8000 m. at low-pressure rotor autorotation r.p.m. equal to 15 - 30 per cent which corresponds to 400 - 650 km/hr IAS.

In-Flight Engine Starting

At an altitude not higher than 12,000 m. and engine autorotation r.p.m. not exceeding permissible ones, the pilot moves the engine control lever to IDLE RATING (AZMP PA3) and locks it in the position, then closes the STARTING IN FLIGHT circuit breaker; at the same time he switches on the starting fuel electromagnetic valve and pump, ignition system and oxygen feed of the main combustion chambers igniters; inscription ENGINE STARTING on the P-6 light panel will illuminate and engine r.p.m. will start to increase.

Note: The starting will be checked by engine r.p.m. increase and sound indication. Jet pipe temperature rises slowly and cannot be accepted as a reliable sign of starting commencement.

CAUTION. The STARTING IN FLIGHT selector switch must not be turned on for more than 30 sec. (to avoid failure of the ignition system coils).

If after 30 sec. the engine fails to start the pilot must open the STARTING IN FLIGHT circuit breaker, return the engine control lever to the CUT -OFF position and, after 15 - 30 sec. of engine air-blasting, re-start the engine.

The pilot will continue his attempt to start the engine up to 2000 m. When this altitude is reached and the engine

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still fails to start the pilot will make a decision to abandon the aircraft or to carry out power-off landing.

Power-off landing will be possible only when the servo hydraulic system is operating normally and with mandatory cut-off of the aileron boosters.

Power-Off Landing Procedure

Power-off landing will be executed on an airfield only.

Prior to landing the pilot proceeds as follows:

(a) moves the engine control lever to the CUT-OFF position;

(b) cuts off pump No.2 and closes the selector valve;

(c) disconnects electric power consumers not used in landing;

(d) checks if the aileron hydraulic amplifiers are off;

(e) checks whether the FIRE EXT UNIT ([illegible] CHARGING) circuit breaker is closed;

(f) checks pressure in the hydraulic system.

At 2000 m. by checking the pressure drop signal light and pressure gauge left-hand pointer indicating pressure in the servo hydraulic system, he makes sure that the booster hydraulic system is operating normally;

Note: The servo hydraulic system is considered normally operative if:

(a) at normal autorotation of the engine, servo hydraulic system pressure is maintained within 180 - 210 kg/sq.cm. limits as indicated by the pressure gauge, and the yellow signal light is not illuminating; in this case all hydraulic fluid drain required for stabilizer control (aileron boosters are off) is compensated by the servo hydraulic system main [illegible] pump;

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(b) in case the servo hydraulic system [illegible]-54 pump fails to maintain this pressure (due to system malfunctioning or due to decrease of autorotation r.p.m. and the latter drops to 165 kg/sq. cm. the emergency [illegible]-27 pumping unit will cut in and the yellow light will illuminate; in this case the pressure in the hydraulic system will be always maintained within 165 - 180 kg/sq.cm. limits and the yellow signal light will be on until landing.

Up to 200 m. the pilot maintains a gliding speed of 420 - 450 km/hr as indicated by the wide pointer, and glides to the point of first flare-out which is 700 m. from approach end of the runway.

Rate of descent in this case will be approximately 35 - 45 m/[illegible]

After making sure that judgement for landing is correct the pilot will use emergency procedures to lower the landing gears.

Flaps and air brakes are not to be used.

On reaching 200 m. the pilot performs first flare-out and establishes such a glide angle that he has got used to when executing normal power-on landing.

By the time 30 - 40 m. are reached the rate of descent must decrease to 4 - 6 m/sec. Right before touchdown, the attitude of the aircraft as to trajectory slope angle and rate of descent will be habitual for the pilot and trajectory speed of 350 - 360 km/hr will be sufficient.

At 15 - 12 m. the pilot performs the second flare-out, using the same procedure as in case of normal power-on landing, brings the aircraft to not more than 1 m. off the runway and executes touchdown.

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Procedure on Encountering Hydraulic System Failure

If both hydraulic systems fail to operate in flight which is indicated by illumination of two pressure drop signal lights and by progressive insistent pressure drop below 165 kg/sq.cm. in both hydraulic systems (checked on pressure gauge), the pilot must abandon the aircraft (though the engine is operative) by using ejection procedure.

If one of the hydraulic systems (either main or servo one) fails which is indicated by illumination of the pressure drop signal light and by pressure gauge readings, the pilot must discontinue execution of his mission. While approaching for landing he should not use the air brakes or flaps and is to follow emergency procedure for landing gear extension with the landing gear control lever being neutral.

If the servo hydraulic system HM-54 pump fails and the HM-27 pumping unit cuts in when the aircraft is more than 15 min. of flight out of the airfield, the pilot will proceed as follows:

(a) after making sure that the pump unit is operative, switches the latter off (to prevent overheating);

(b) on approaching the airfield switches on the HM-27 pumping unit to build up pressure in the servo hydraulic system.

Power-off landing will be performed only if the servo hydraulic system is operating normally.

In case of servo hydraulic system failure (pressure drops below 165 kg/sq.cm.), power-off landing must not be attempted and the aircraft should be abandoned by means of ejection.

Procedure on Encountering Fuel Pressure Drop

Illumination of inscription SERVICE TANK on the fuel light panel will indicate that fuel pressure after the fuel pump has dropped. In this case the pilot has to select normal panel

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thrust or lower power setting, descend to 7,000 m. or lower and discontinue execution of the mission. The pilot must avoid negative G-loads to forestall engine cut-off.

Procedure on Encountering Engine Oil Pressure Drop

In case oil pressure drops to zero, the pilot must discontinue his mission, decrease engine r.p.m. and land at once.

Procedure in Case of Engine Fire

Indications of fire are as follows:

(a) illumination of inscription FIRE on the T-6 light panel;

(b) smoke trail behind the aircraft (is detected during a turn).

To extinguish fire it is necessary:

(a) to retard the engine control lever to position CUT-OFF;

(b) to push button CUT-OFF VALVE (ПРЕКРЫВАТЕЛЬ КРАНА);

(c) to decrease speed to 450-500 km/hr and to assume climbing attitude;

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(d) to push the button FIRE EXTINGUISHER of the anti-fire system.

This done, the pilot makes a decision to land or to bail out depending upon the situation.

The engine must not be re-started if the anti-fire equipment has been used.

Procedure in Case of [illegible]-1 and [illegible]-156 Tubes Failure

Failure of the static-pressure system as well as the static-and total-pressure systems fed on the pitot-static [illegible]-5 tube, can be detected by wrong readings of speed indicator, altimeter, rate of climb indicator, M-number indicator, the [illegible]-3E automatic transmission ratio control unit indicator and cone control indicator, while failure of only total-pressure system fed on the [illegible]-5 pitot-static tube is detected by means of the readings of speed indicator, M-number indicator, the [illegible]-3E automatic unit indicator and cone control indicator.

In case of simultaneous failure of only speed indicator and M-number indicator as well as of the [illegible]-3E automatic unit indicator and cone control indicator, the pilot must change the [illegible]-5 pitot-static tube supply of these instruments by the emergency [illegible]-156 total-pressure tube supply, discontinue his mission and land.

In case of simultaneous failure of all instruments or if the latters fail to restore their functioning after they have been switched over to the emergency [illegible]-156 total-pressure tube supply, the pilot should discontinue his mission and proceed to the airfield, taking advantage of the artificial horizon, turn indicator, and r.p.m. indicator readings and at altitudes below 600 m. also of the [illegible]-V radio altimeter readings and landing condition of flight by ground radio facilities data.

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Notes: 1. Failure to switch on the ПВД-5 pitot-static tube and the ТП-156 total-pressure tube heating may lead to icing of these tubes and consequently to malfunctioning of the instruments connected to these tubes. If this is the case, the instruments must resume their indication 2 - 3 min. after the heating has been switched on.

2. If failure occurs when the aircraft is flying at afterburning power setting, the pilot should cut afterburner off and then retard the extending cone to the initial position manually after the aircraft has been slowed down.

3. In case of simultaneous or partial failure of the instruments, the АРУ-3В automatic unit will be reset from HIGH SPEED to LOW SPEED prior to landing. It must be borne in mind, though, that traction of the executive mechanism rod takes 18 - 20 sec.

Procedure on Encountering Aircraft Icing

If the pilot encounters icing of the aircraft and canopy during upward cloud penetration, he must climb above clouds and switch on the de-icing system in level flight; the system will be switched on by impulses of 2 - 3 sec. duration with 10 - 15 sec. intervals.

If icing occurs during downward cloud penetration, the pilot will maintain the condition of flight and will use the de-icing system at 1000 m. and below.

To facilitate removal of ice formation from the aircraft the pilot will increase flying speed (if flight condition permits); at medium altitudes to 700 km/hr IAS and at high altitudes to 800 - 900 km/hr TAS.

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Procedure on Encountering Oxygen System Failure

Oxygen system failure is indicated by:

(a) abrupt drop of oxygen pressure in the system (as indicated by the pressure gauge);

(b) cut-off of oxygen supply to the pressure helmet mask (which is detected by a pill blinker on front of the [illegible] oxygen-flow indicator when in that position);

(c) the [illegible] oxygen regulator failure to build up suitable pressure in the high altitude pressure helmet and making breathing difficult, in the pressure helmet or in the mask (the [illegible] oxygen overpressure gauge will show zero pressure), when cockpit depressurization occurs at altitude (as indicated by the [illegible] altitude and pressure differential gauge) rises more than [illegible] the oxygen supply on).

Immediate notice by [illegible] of the above [illegible] oxygen system failure, he must immediately switch on the [illegible] oxygen apparatus and [illegible] the emergency landing [illegible] descend to [illegible] altitude.

While descending he must make sure that the air-filter valve in the [illegible] of the [illegible] panel is [illegible].

Switching on the [illegible] permits any [illegible] manually without disconnecting the [illegible] motor [illegible] of the air-filter [illegible] is possible [illegible] indispensable and mandatory to provide for [illegible] dilution of oxygen with the air that from the [illegible] atmosphere via the [illegible] oxygen regulator when [illegible] supplied by the [illegible] apparatus is not sufficient for [illegible].

Procedure in Case of Cockpit Depressurization at High Altitude.

When cockpit depressurization is not [illegible] by [illegible]

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of the canopy glass or by blowing off of the collapsible part of the canopy, the pilot has to descend to attain cockpit "altitude" of 12,000 m. and less, at which it is allowed to perform durable flight and proceed with execution of the mission provided there is no other failures.

In case the canopy glass is damaged or canopy collapsible part is blown off, the pilot will immediately and in shortest time possible decrease altitude and flying speed. With the canopy glass damaged or canopy collapsible part blown off he is allowed to fly at a speed not exceeding 500 km/hr if a helmet is worn, and at a speed not exceeding 700 km/hr when he wears a pressurized helmet.

Procedure on Encountering Smoke in Cockpit

When the pilot detects smoke in the cockpit, he proceeds as follows:

(a) changes over to pure oxygen supply; for this purpose he turns the air-dilution handle, which is installed on the AV-2 panel, to the PURE OXYGEN position;

(b) switches off the cockpit supercharging by moving the supercharging cock handle on the starboard panel full back and descends to an altitude below 12,000 m.;

(c) if smoke continues to flow into the cockpit, the pilot decreases flying speed and altitude and takes measures required by the situation right up to canopy jettisoning.

Procedure on Encountering Canopy Glass Misting

In case of canopy glass misting the pilot has to check if the cockpit air supply cock is open and the canopy is sealed, to increase engine r.p.m., to select the HOT position

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the cockpit air supply temperature regul for switch and to increase rate of descent.

Landing Gear Emergency Extension Procedure

If the landing gears cannot be lowered normally (pressure not available in the main hydraulic system), the pilot will use landing gear emergency extension procedure. For this purpose he proceeds as follows:

(a) sets the landing gear control handle control;

(b) opens the landing gear emergency extension cock;

(c) checks landing gear extension by the signal lights (green) and by putting-out of the mechanical indicators and then performs landing.

Procedure in Case of Generator Failure

Generator failure can be detected by illumination of inscription [illegible] (illegible) on the [illegible] panel and by voltmeter (voltage will drop from 28 - 29 V to storage battery voltage level which is equal to 22 - 23 V). In case of generator failure it is necessary:

(a) to discontinue the mission;

(b) to advise the tower on the failure;

(c) to switch off the following consumers: pump No.2 (at an altitude below 7000 m.), No.3 [illegible]; the [illegible] automatic radio compass, the [illegible]-1 aircraft transponder and the [illegible] VHF communication radio set will be switched on temporarily, in turn and in case of necessity.

If the generator fails and the electric power consumption on the aircraft storage batteries according to the procedure mentioned above (both during daytime and night flying), the aircraft can fly safely for 25 - 35 min.

Notes: 1. In case of generator failure the following

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instruments are automatically cut off: sight and its heating system, radio-range finder, the ОПР-52 infra-red sight, the РВ-У radio altimeter, the МРП-56М marker receiver and pumps Nos 1, 4 and 5.

2. If circuit voltage drops below 20 V, the landing gear will be lowered by emergency procedure. In this case the pilot must bear in mind that the brake chute may fail to eject.

ПО-750А Inverter Failure

Failure of the ПО-750А inverter feeding the РСИУ-5Р VHF communication radio set, the АРК-10 automatic radio compass, the СРО-1 aircraft transponder, the ДИМ-6Т remote-indicating induction pressure gauge, the РТС-16А-4 fuel flowmeter, the ИС-2 ionizing fire detection unit, can be ascertained by the pilot during flight through disappearance of radio communication (on all channels), radio compass failure to respond to aircraft deviation from an established relative bearing, malfunctioning of the fuel flowmeter indicator (the fuel flowmeter dial is motionless).

If all these signs are manifested the pilot has to close the INVERTER EMERGENCY SWITCH circuit breaker installed on the front starboard electrical subpanel. This will connect all the above mentioned consumers to the other ПО-750 А inverter, and the pilot will detect it by resumed functioning of the instruments after radio tubes have warmed up (after 1 - 1.5 min).

At the same time the consumers on aircraft of 1st, 2d and 3rd series (these are the АСИ-5МЦ sight with heating, СРД-5М, СИВ-52, РВУ, МРП-56) operating on the second ПО-750 А inverter will cut off.

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In case of later series aircraft, only the AFK-[illegible] with heating, [illegible]-2 [illegible] will cut off.

Procedure in case of AFK-1 Radio Compass failure

The [illegible] automatic radio compass fails [illegible] its point on the NDB. The radio compass [illegible] aircraft still [illegible] will not respond to aircraft heading or will rotate incessantly.

In determining this phenomenon and after making sure that fuel flow [illegible] and radio set operate normally, the pilot [illegible] requests the [illegible] officer's information on operation of NDB. If the [illegible] officer confirms that the NDB is operative, the [illegible] will check:

(a) position of power-band selector switch (when the aircraft homes on constant frequency [illegible] the switch must be in position WIDE (SHIR.);

(b) position of concentric detents on the range selector [illegible] course tuning knobs;

(c) position of the RANGE ([illegible]) [illegible] and indication of the course tuning scale to verify proper [illegible] of frequency for tuning the radio compass to the [illegible] NDB;

(d) proper tuning of the radio compass by maximum [illegible] of the tuning indicator pointer to the right;

(e) position of the selector switch INNER-OUTER [illegible]: [illegible]);

(f) operation of the radio compass on other fixed channels of tuning.

In case of the AFK-10 automatic radio compass complete failure, the pilot has to discontinue his mission and to carry out DF and radar approach.

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Procedure in Case of Radio Set Failure

On encountering radio communication failure and after making sure that the fuel flow meter and radio compass are operative, the pilot checks:

(a) position of the microphone selector switch installed on the [illegible] communication radio set control panel (the switch must be in position RADIO);

(b) helmet (pressurized helmet) adapter line connector contact;

(c) position of the switches on the control panel of the [illegible] amplifier installed on the cockpit port (if the pressurized helmet is worn they must be in positions [illegible] and [illegible], i.e., turned up).

On accomplishing these checks the pilot turns the volume control knob to full volume position and switches off the interference suppressor by turning to interference supressor: ON-OFF tumbler switch located on the radio set control panel to the OFF position (noise and cracking must appear in the earphones).

If radio contact cannot be re-established on operating frequency, the radio set will be checked on other frequencies.

In case the pilot fails to contact the tower on other frequencies too, he must proceed on his airplane and return to his airfield.

If the [illegible] provided with additional equipment which allows the ATC officer to issue his instructions through this NDB, the pilot will use the [illegible]-10 receiver to follow the ATC officer's instructions which will guide him to the airfield.

For this purpose the pilot will turn the STATION-TO-STATION COMPASS-TO-COMPASS([illegible]) selector switch on the radio set control panel to the COMPASS position, duty selector switch on the APK-10 control panel to the ANTENNA position and the VOICE-KEY selector switch to the VOICE position.

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For the purpose of checking the [illegible] to the [illegible] pilot [illegible] panel [illegible] the [illegible] selector [illegible] panel [illegible] for [illegible].

In all the cases of radio communication failure the pilot [illegible] the emergency [illegible] report, [illegible] the flight [illegible], [illegible] the [illegible] [illegible].

Procedure of [illegible] failure

In case of the [illegible] automatic transmission [illegible] manual [illegible] failure, the pilot has to [illegible] the [illegible] then change over to manual control of the [illegible] to execute [illegible].

For this purpose, he will turn the selector [illegible] panel from position [illegible] to position [illegible] and then use manually the [illegible] pressure switch [illegible] it in the [illegible] motor [illegible] motion. The [illegible] position corresponds to the [illegible] of the [illegible] unit rod, and [illegible] to large [illegible].

While controlling the [illegible] motor the [illegible] manually, the pilot should [illegible] particular attention to the [illegible] indicator readings and compare them with speed indicator [illegible] indicator readings.

IAS must not exceed the speed, to which the [illegible] position corresponds, by more than [illegible] km/h. Otherwise the aircraft may experience rocking due to [illegible] when the [illegible] unit rod and position [illegible] rod.

When the [illegible] automatic unit electric [illegible] controlled manually, the pilot can carry out only level [illegible] both evolutions and landing.

In case the [illegible] unit fails while in small [illegible] (due to electric motor failure) and the pilot [illegible] the

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turn its executive mechanism to take-off-landing position (i. large arm position), he will decrease IAS and land with the ATY unit rod in small arm position.

Landing with the ATY unit rod in small arm position requires higher attention and accurate movements; it must be remembered that in this case stabilizer deflection angle decreases by half, forces on the stick augment and touchdown speed increases. Therefore, gliding speed should be increased by 20 - 30 km/hr and gliding will be performed with lower angle of flight path slope.

The pilot should keep it in mind, while using the "trimming effect" mechanism at any flight condition, that the mechanism takes 9 - 12 sec. to change its extreme positions.

Procedure in Case of Cone Control System Failure

Cone automatic control system failure is manifested in:

(a) cone failure to extend when the aircraft is accelerated to M-number equal to 1.5 or 1.9 (the signal light on the T-4 light panel does not illuminate and intake duct sound does not change);

(b) cone failure to retract when the aircraft is slowed down to M-number equal to 1.9 or 1.5 and less.

If the cone fails to extend the pilot should not accelerate the aircraft above M=1.5 and will extend the cone manually if the flight is to be continued. In case the cone fails to retract at M=1.9 the pilot will firstly select position 1.5 for the cone manual control switch and then turn the duty selector switch to the MANUAL (РУЧНОЕ) position; after M=1.5 is reached the manual control switch will be rest to the RETRACTED (УБРАНО) position.

If at M-1.9 the cone has automatically moved to the inter

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[illegible] position but fails to retract fully [illegible] (at [illegible] [illegible] - [illegible] [illegible] [illegible] [illegible] go off), for retraction the pilot will leave the manual control switch in [illegible] position and will turn the duty selector switch to [illegible] position.

In case the cone cannot be retracted manually, the pilot [illegible] discontinue the mission and to avoid r.p.m. increase [illegible] 95 per [illegible] during return flight.

Procedure in Case of Air Intake Surge

Air intake surge manifests in a surgeed of flops in the intake [illegible], which will be felt by the pilot.

If air intake surge occurs when the aircraft is accelerating to M=1.5 [illegible] more, the pilot proceeds as follows:

(a) cut out afterburner;

(b) assume [illegible] climbing attitude and slow the aircraft down.

If these [illegible] fail to eliminate the surge the pilot [illegible] shutters manually after [illegible] the outer cone [illegible] position. All [illegible] to position [illegible].

After the surge [illegible] the aircraft [illegible] slowed down to M=number equal to less than 1.5, the outer switch [illegible] return [illegible] position [illegible].

If the above procedures fail to cease the surge, the control lever [illegible] be retarded to the [illegible] position [illegible].

Procedure in Case of Flat Tyre During Take-Off

Flat tyre during take-off roll will be felt [illegible] side of the aircraft, exerting moment [illegible] aircraft [illegible] the flat.

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In case of a flat tyre on a main wheel during the first half of take-off roll, it is necessary:

(a) to discontinue take-off;

(b) to keep the aircraft from swerving and to eject the brake chute.

If a flat tyre occurs during the second half of take-off roll the pilot will continue take-off, brake the wheels after unstick and prior to retracting the landing gears.

Unprepared Strip Landing Procedure

The pilot is allowed to perform forced landing on an unprepared strip only with the engine operating normally and the landing gears down (or the nose wheel strut down).

In this case the pilot proceeds as follows:

(a) drops the ventral tank if the latter contains fuel;

(b) at 450 - 500 km/hr jettisons the canopy by pulling the canopy jettison handle, located on the cockpit starboard;

(c) prior to touchdown locks the safety belts and cuts off the engine and the battery.

Procedure in Case of Emergency Exit on Ground

If it becomes necessary to abandon the aircraft on the ground urgently, the pilot will have to:

(a) open the canopy if it has not been jettisoned before by pulling back the canopy control handle (on cockpit port); if the canopy fails to open (which indicates that air is not available in the aircraft system or that the locks have jammed) it is necessary to use canopy emergency jettison procedure, i.e., to pull back the canopy jettison handle which is on the cockpit starboard;

CAUTION. While jettisoning the canopy the pilot should lean as much forward as possible.

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(c) [illegible]

(d) [illegible];

(e) [illegible] safety belt [illegible] by hand, [illegible] the safety harness automatically [illegible] [illegible] or the [illegible] front [illegible].

[illegible] Failure of the Jettison Control in [illegible]

The [illegible] carried out [illegible] power [illegible] if the jettisonable canopy control in the [illegible] ejective [illegible] does not [illegible] the [illegible] control [illegible] [illegible] [illegible] power to the [illegible] power, or [illegible] power of [illegible] ejected), the pilot will turn on the [illegible] UNPRESSURIZE [illegible] [illegible] to two-position system of the jettisonable canopy [illegible] will [illegible] power, in this case, [illegible].

Procedure in Case of Emergency Launching of [illegible] Special Missiles

For emergency launching of special missiles the pilot [illegible] the [illegible] EMERGENCY LAUNCHING [illegible]. [illegible] Then, after the button has been pushed, the special [illegible] will leave the launching device and [illegible] [illegible], [illegible] [illegible].

Missile Emergency Drop Procedure

When missile emergency drop becomes necessary, the pilot will push the emergency drop button (the [illegible]) and the [illegible] door is to be closed before [illegible] and the missiles will go down together with the [illegible].

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Procedure in Case of Ejection with Canopy Protection

Prior to abandoning the aircraft, the pilot must:

(a) decrease flying speed (if conditions permit);

(b) take the seat arms with hands and squeeze one of them or both.

Further process of ejection including parachute opening is automatic, without pilot's interference. Minimum ejection altitude in level flight is 110 m. Safe speed of ejection (V_{IAS}) is [illegible] km/hr.

Procedure in Case of Ejection after Canopy Jettisoning

Prior to ejection the pilot has:

(a) to turn down and pull back the red handle (which is in the starboard side panel); this will release the canopy;

(b) to take seat arms with hands and squeeze one of them or both.

After ejection and following the safety belt lock disengagement the pilot will push the seat away, and, after separation from the seat, will open his parachute on expiration of time indicated below.

When ejection takes place at altitudes below 500 m., the pilot should lose no time in opening the safety belt lock, separation from the seat and in opening the parachute.

If the aircraft is abandoned at altitudes above 5000 m. the pilot must delay parachute opening to 4000-3000 m, to avoid strong dynamic shock (if the KAH-3 apparatus is not available).

In case the parachute is equipped with the KAH-3 apparatus the pilot will wait for automatic opening of the parachute up to 1000 m.

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The [illegible] parachutes are to be opened with the following [illegible] after separation from the seat:

(a) [illegible] 2 sec. at altitudes up to [illegible] m;

(b) [illegible] 5 sec. at [illegible] m.

When ejection occurs at altitudes above [illegible] m., the parachute must be opened only after 1 [illegible] delay for each [illegible] m. (Table 11).

Table 11

Ejection altitude, m.	[illegible]	11,000	12,000	13,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Required delay for parachute opening, sec.	10	20	30	40	50	[illegible]	[illegible]	[illegible]	[illegible]

If the [illegible] is to be [illegible] the pilot [illegible] the cockpit is depressurized, the pilot [illegible] below the [illegible] and straighten [illegible] of the [illegible] shoulders [illegible] are inflated with [illegible] before will be required to assume protection [illegible] fragment of the feet on the foot rests and [illegible] of [illegible] to straighten the face curtain). Ejector proper is also [illegible] as described above.

Procedure of High Altitude Bailing Out in Case of Seat Firing Mechanism Failure

If after both levers have been pressed the seat [illegible] the pilot will:

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(a) decrease flying speed (if the conditions permit);

(b) turn on the KH-27 apparatus oxygen emergency supply by pulling the KH-27 oxygen apparatus opening handle;

(c) open 3PX common connector by pulling the connector upper block lever or the emergency holder (connected to the oxygen supply hose);

(d) pull the emergency holder, located on the seat fire pan between pilot's legs; this will operate the leg and shoulder straps restraint guns which will relieve the pilot of the seat harness (the emergency holder will remain in pilot's hand);

(e) use emergency procedure to jettison the canopy by pulling the red handle back (the handle is located on the cockpit starboard);

(f) abandon the aircraft;

(g) remove the pressurized helmet face-piece on reaching safe altitude.

Procedure in Case Canopy Fails to Separate from Seat after Ejection

If 1.5 sec. after ejection the canopy fails to separate from the seat, the pilot will have to pull the emergency holder, located on the seat pan between pilot's legs, to operate the leg and shoulder straps restraint guns which will relieve the pilot of the seat harness and separate the canopy from the seat.

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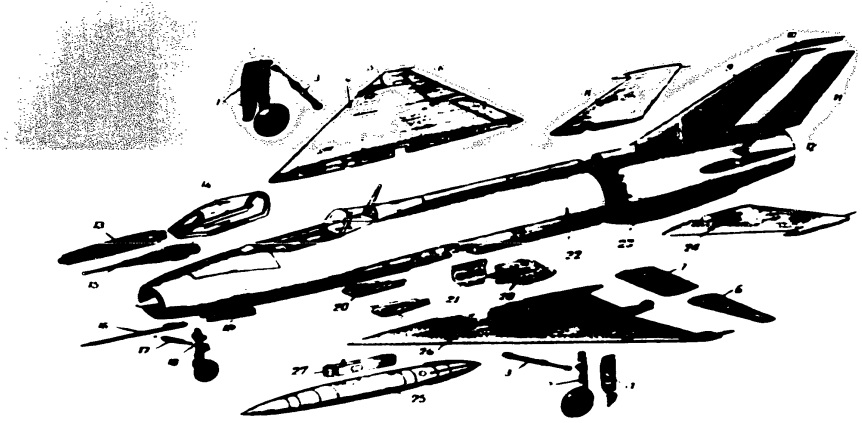

FIG. 1. STRUCTURAL JOINTS OF AIRCRAFT

1 – main L.G. strut doors; 2 – main L.G. strut; 3 – main L.G. actuating cylinder; 4 – starboard outer panel; 5 – wing bonnet; 6 – aileron; 7 – wing flap; 8 – stabilizer starboard section; 9 – fin; 10 – fin top; 11 – rudder; 12 – aft fuselage section; 13 – gun fairing; 14 – canopy; 15 – gun; 16 – pitot-static tube; 17 – nosel.G. actuating cylinder; 18 – nose L.G. strut; 19 – nose L.G. strut doors; 20 – air brakes; 21 – main L.G. well door; 22 – fuselage forward section; 23 – underwing fuselage bonnet; 24 – stabilizer port section; 25 – drop tank; 26 – port outer panel; 27 – pylon.

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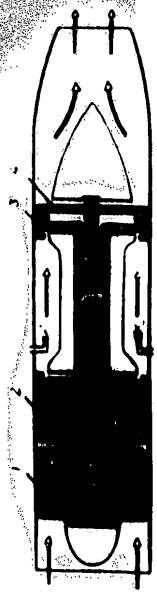

FIG. 2. BASIC DIAGRAM OF TWO-SHAFT TURBOJET ENGINE

1 – low-pressure compressor; 2 – high-pressure compressor; 3 – high-pressure turbine; 4 – low-pressure turbine

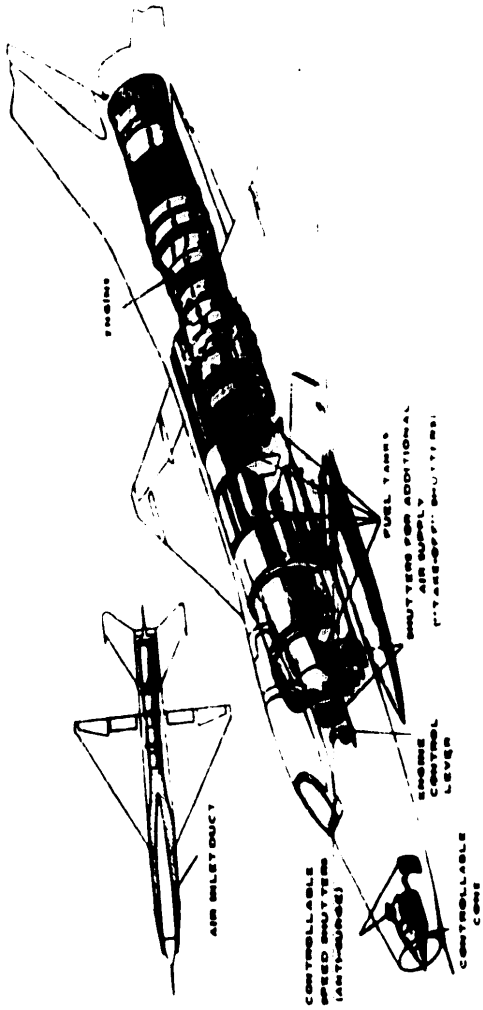

FIG. 3. POWER [illegible] DIAGRAM

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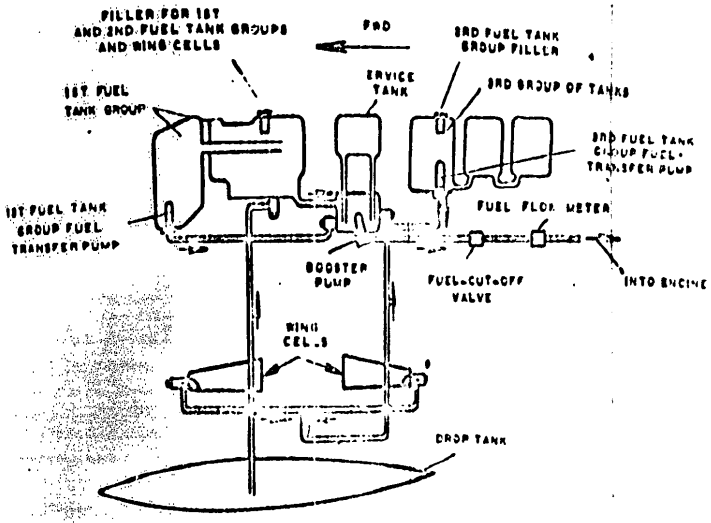

FIG. 4. BLOCK DIAGRAM OF AIRCRAFT FUEL SYSTEM

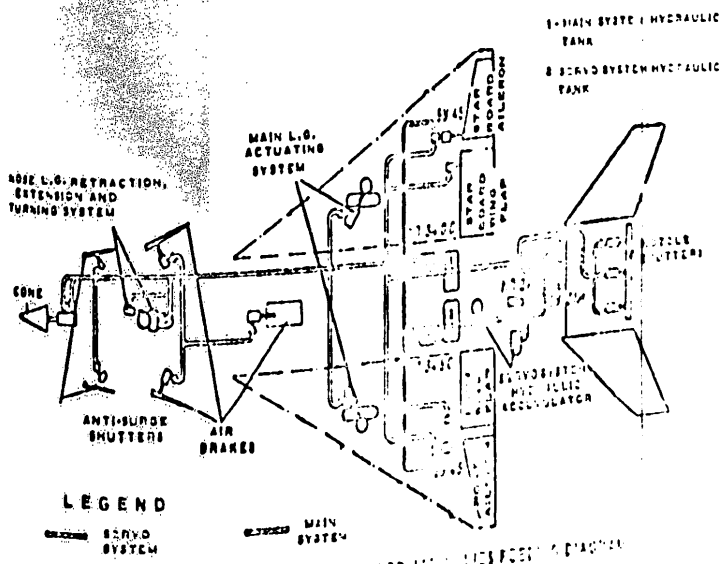

FIG. 5. HYDRAULICALLY CONTROLLED [illegible]

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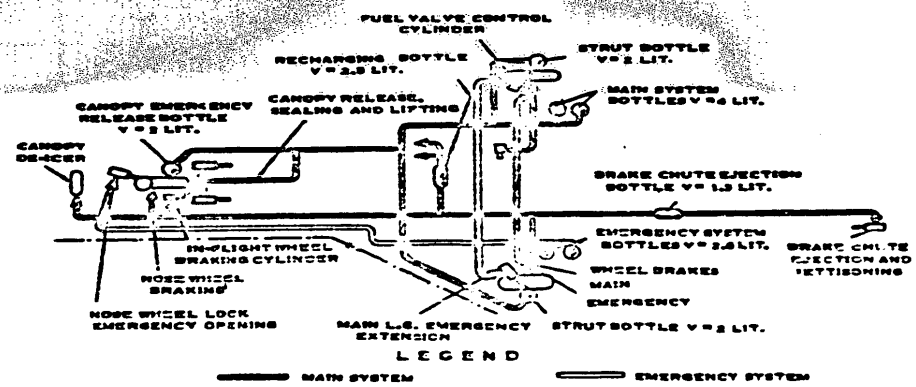

FIG. 6. PNEUMATICALLY CONTROLLED ASSEMBLIES FEEDING DIAGRAM

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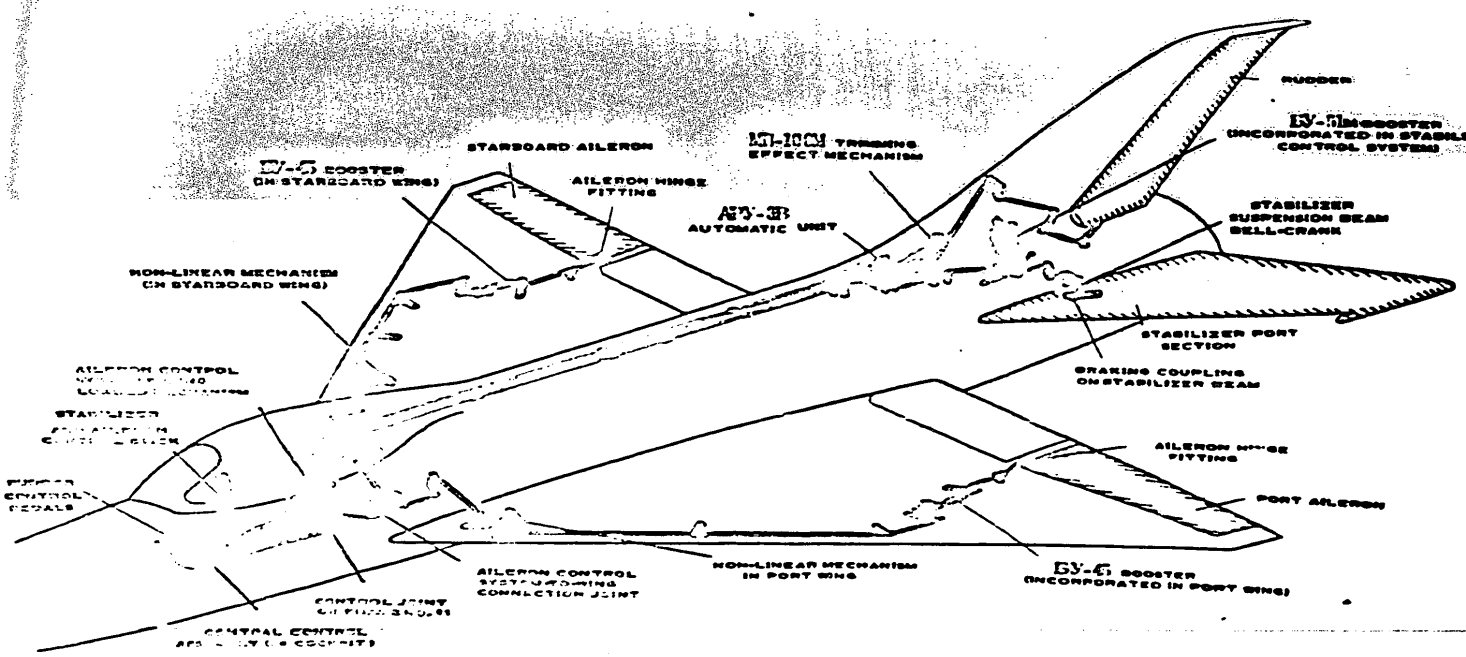

FIG. 7. AIRCRAFT CONTROLS

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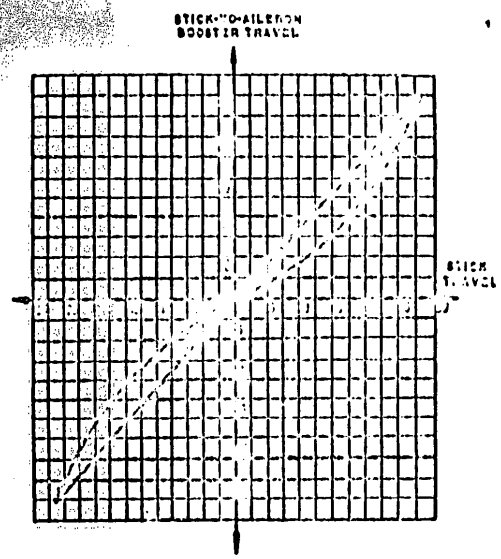

FIG. 8. GRAPH OF AILERON CONTROL MECHANISM NON-LINEAR TRANSMISSION

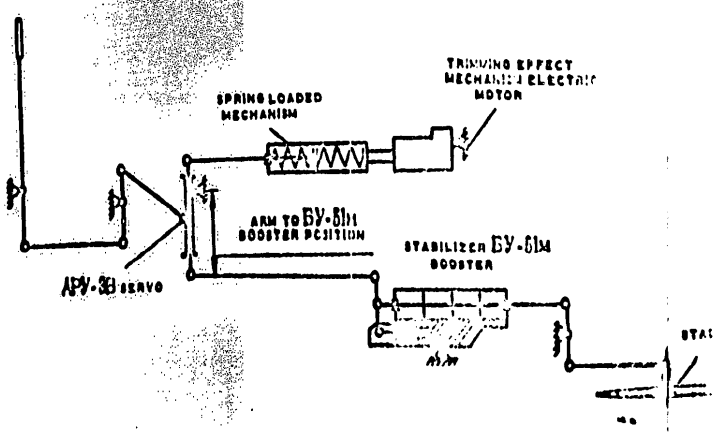

FIG. 9. BLOCK KINEMATIC DIAGRAM OF STABILIZER CONTROL SYSTEM

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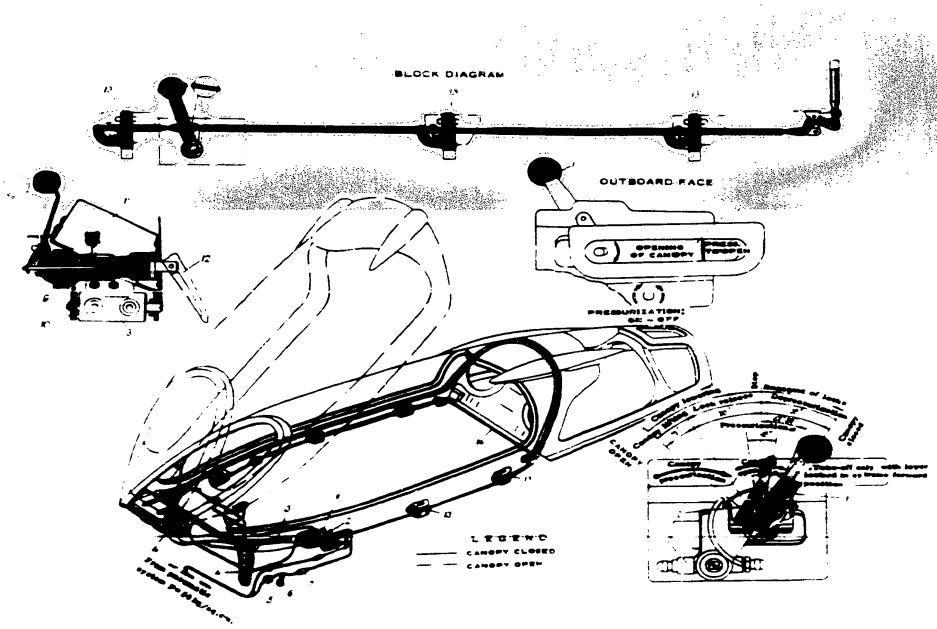

FIG. 10. CANOPY PRESSURIZATION AND CONTROL SYSTEM

1 – internal canopy control handle, 2 – pressurization handle; 3 – control and pressurization cock; 4 – lifting lock, 5 – PB-1 5 reducer; 6 – safety valve, 7 – non-return valve, 8 – pressurizing hose, 9 – gear quadrant; 10 – gear; 11 – handle-to-emergency release rod bell-crank, 12 – external canopy control handle, 13 – pin 14 – lateral rod.

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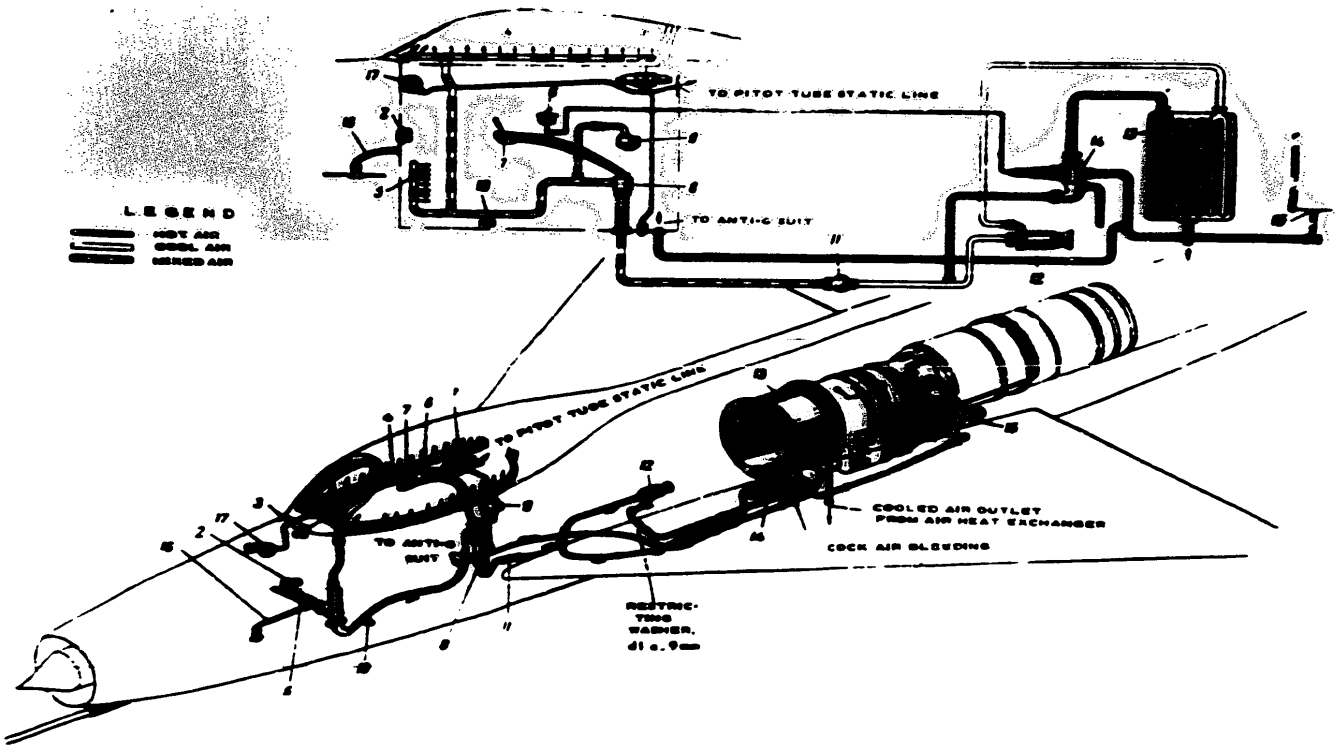

FIG. 11. COCKPIT SUPERCHARGING SYSTEM

1 – cockpit pressure controller; 2 – safety valve; 3 – cockpit altitude and pressure differential gauge; 4 – canopy collapsible part blowing collector; 5 – pilot's leg blowing collector; 6 – four-position switch; 7 – cockpit supply cock control handle; 8 – cockpit supply cock; 9 – TPTBK-48M temperature regulator; 10 – cock limiting air supply to collectors; 11 – supercharging 78 251 non-return valve; 12 – turbocooler – assembly 477; 13 – air heat exchanger; 14 – air distribution electrical cock; 15 – engine air transfer tube; 16 – cockpit ground ventilation connecting pipe; 17 – 5265 pressure control-ler valve.

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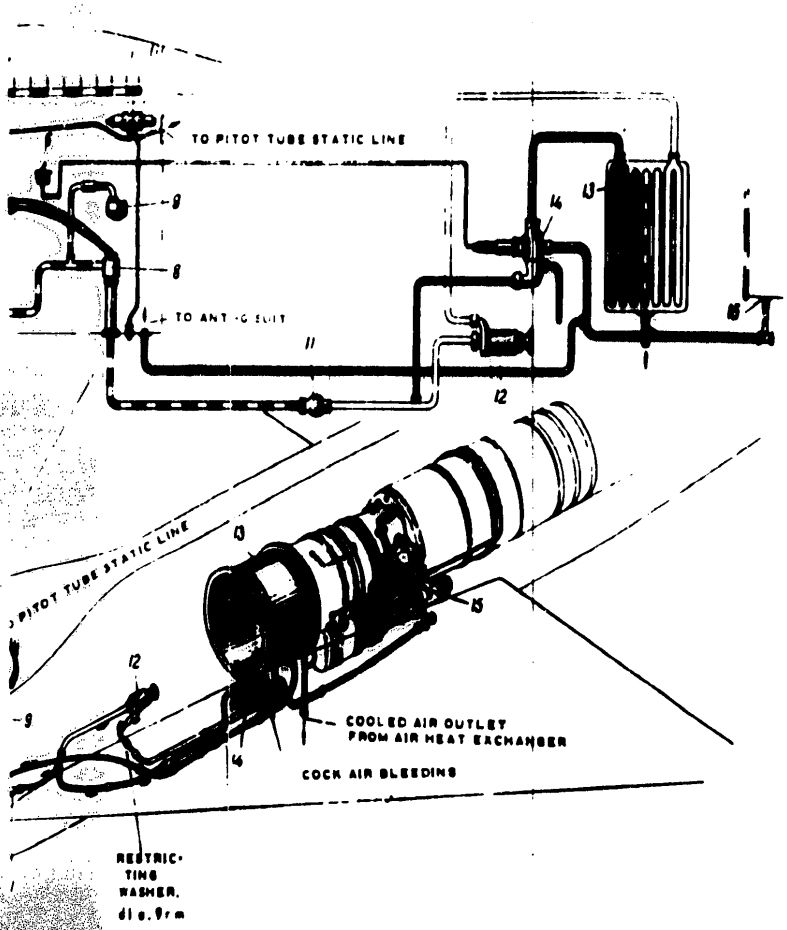

COCKPIT SUPERCHARGING SYSTEM

Altitude and pressure differential gauge; 4 – canopy collapsible port blowing collector; cockpit supply cock control handle; 8 – cockpit supply cock; 9 – TP 1BK-45M temperature [illegible] supercharging [illegible] non-return valve; 12 – turbocooler – assembly 477; 13 – air heat [illegible] transfer tube; 16 – cockpit ground ventilation connecting pipe; 17 – 5205 pressure controller valve.

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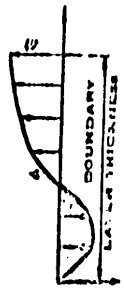

FIG. 13. PROFILE OF BOUNDARY LAYER SECONDARY SPEEDS

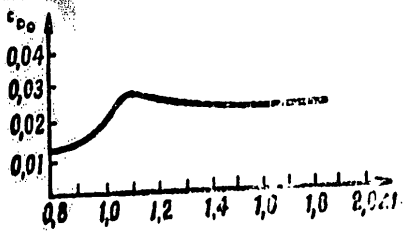

FIG. 12. VARIATION OF MiG-21φ-13 AIRCRAFT DRAG COEFFICIENT ACCORDING TO M-NUMBER AT ZERO LIFT FORCE

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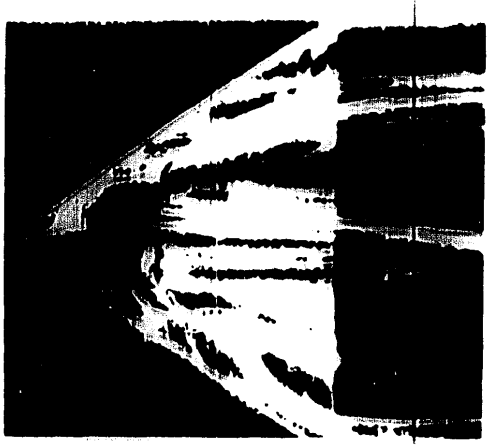

FIG. 14. BOUNDARY LAYER ON SHARP LEADING EDGE DELTA WING UPPER SURFACE

FIG. 15. EXTERNAL STREAMLINING OF SHARP LEADING EDGE DELTA WING UPPER SURFACE

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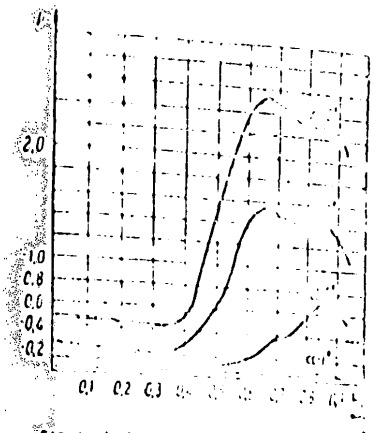

FIG. 16. VARIATION OF [illegible]
DELTA WING SPAN ACCORDING TO ANGLE OF
ATTACK

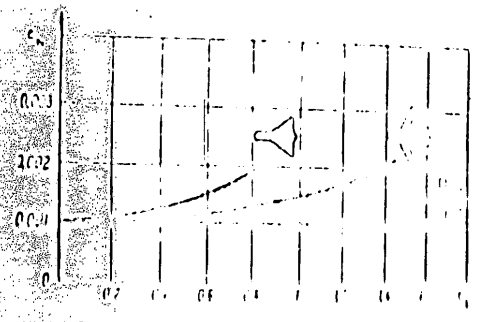

FIG. [illegible]

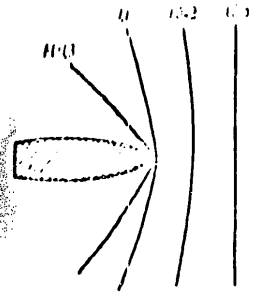

FIG. 1[illegible]. PRESSURE SHOCK FRONT
DEFLECTING ON [illegible] FLOW
[illegible]

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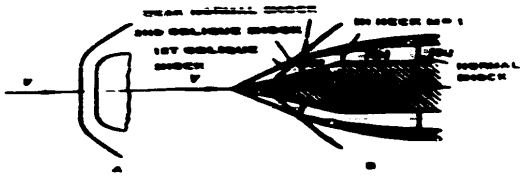

FIG. 19. SUBSONIC (A) AND SUPERSONIC (B) AIR INTAKES

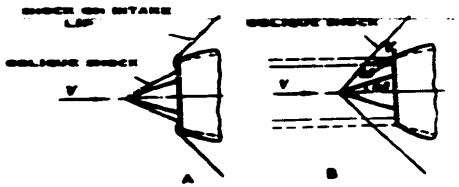

FIG. 20. PRESSURE SHOCK VARIATION AT M NUMBER ABOVE (A) AND BELOW (B) RATED M-NUMBER

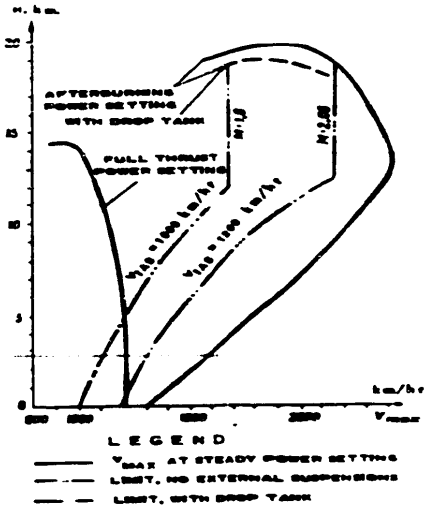

FIG. 21. LEVEL FLIGHT MAXIMUM SPEEDS AT AFTERBURNING AND FULL THRUST POWER SETTINGS

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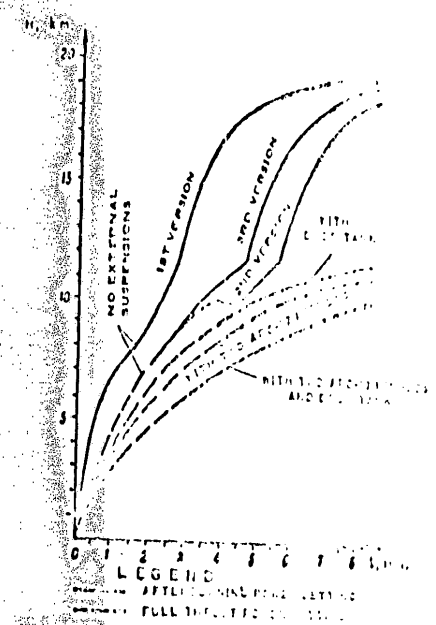
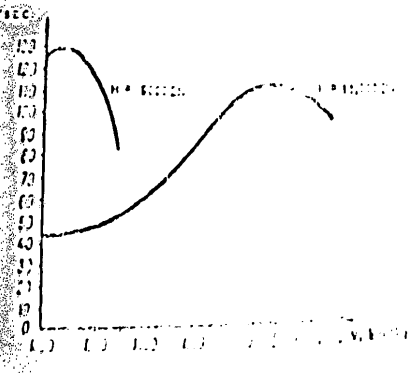


FIG. 22



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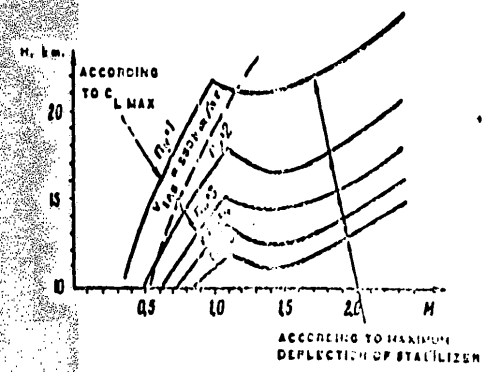

FIG. 24. NET G-LOADS OF [illegible]-21Д-13 AIRCRAFT

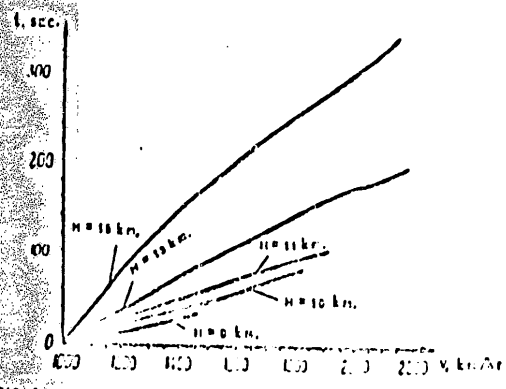

FIG. 25. ACCELERATION TIME AT APPROACHING FOR SUPERSONIC

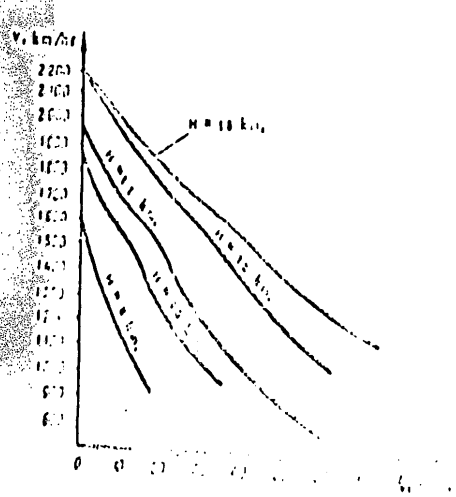

FIG. 26. [illegible]

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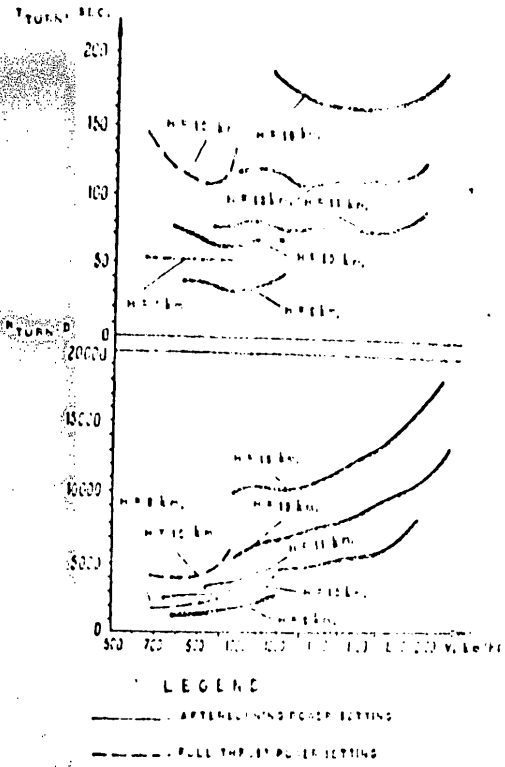

FIG. 27. GRAPH OF TURN RATES AND DURATIONS FOR [illegible] AIRCRAFT CARRYING NO EXTERNAL STORES

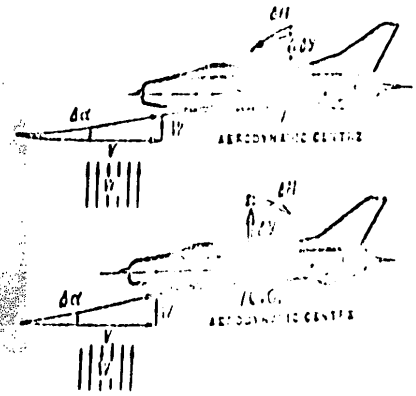

FIG. 28. INTERRELATION OF AERODYNAMIC CENTRE AND CENTRE OF GRAVITY [illegible] AIRCRAFT

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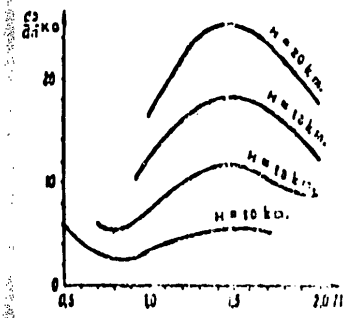

FIG. 29. GRAPH OF VARIATION OF LOAD EFFORT GRADIENT OF [illegible]-13 AIRCRAFT CARRYING NO EXTERNAL SUSPENSIONS

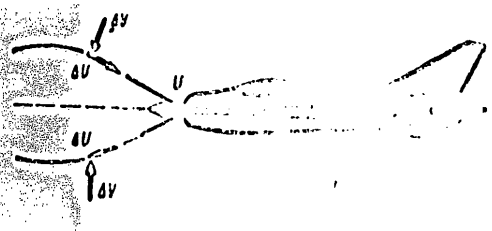

FIG. 30. VARIATION OF LIFT FORCE OF AIRCRAFT STABLE AS TO SPEED CAUSED BY SPEED CHANGE

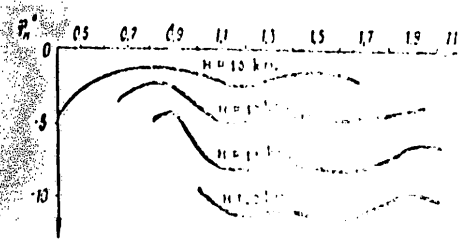

FIG. 31. [illegible]

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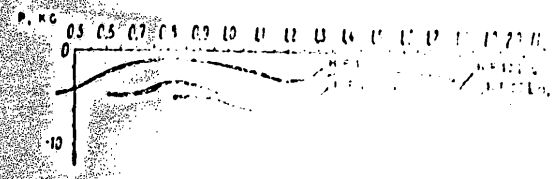

FIG. 32. GRAPH OF FORCES ON CONTROL SURFACES [illegible] FLIGHT AT AFTER [illegible]

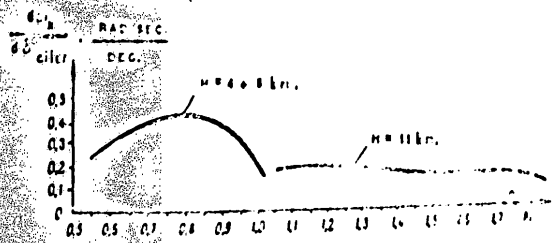

FIG. 33. VARIATION OF [illegible] AS A FUNCTION OF SPEED OF ROTATION AROUND LONGITUDINAL AXIS DEPENDING ON NUMBER AND ALTITUDE

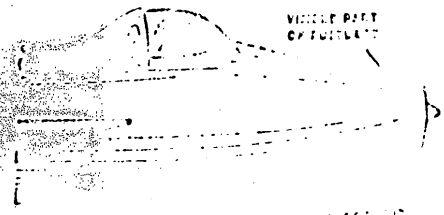

FIG. 34. NORMAL FORCE OF THE FUSELAGE

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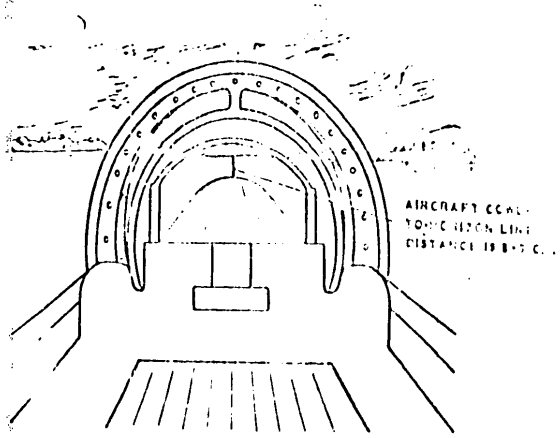

FIG. 35. NOSE-UP ATTITUDE OF AIRCRAFT AT TAKE-OFF

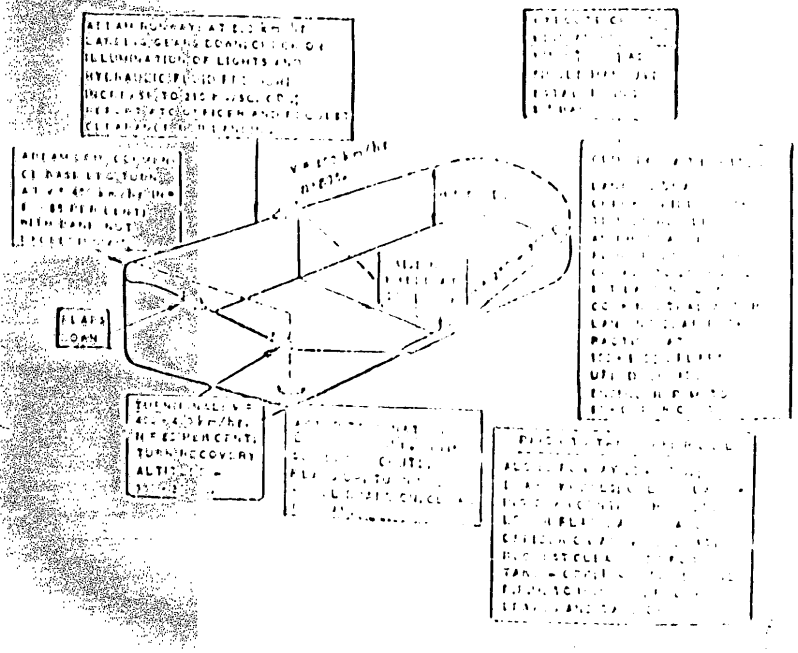

FIG. [illegible]

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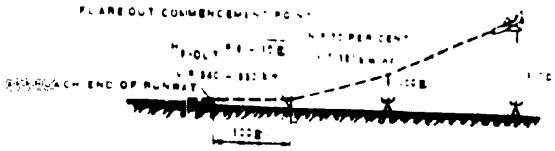

FIG. 37 FLAREOUT POINT POSITION RELATIVE TO RUNWAY

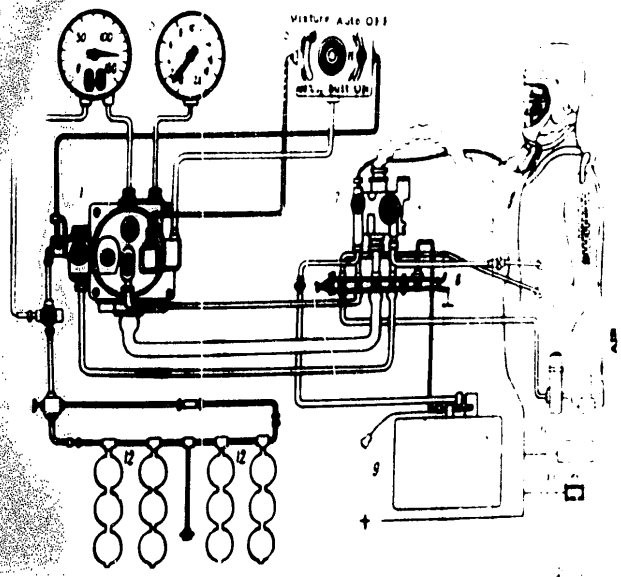

FIG. 38. OXYGEN EQUIPMENT SET

1 – КП-24 oxygen regulator; 2 – ВКК-2М high altitude pressure cell; 3 – ГШ-4М pressurised helmet, 4 – ИК-18 oxygen indicator; 5 – МК-2000 excessive pressure gauge; 6 – ДУ-2 remote control panel, 7 – РСД-2 mask pressure ratio regulator; 8 – ОРК-2 common connector; 9 – КП-27 parachute oxygen apparatus; 10 – pressurised helmet rapid heating 208К button and РКО-45 heating adjustment rheostat, 11 – УК-2М amplifier; 12 – four spherical two-litre capacity oxygen bottles.

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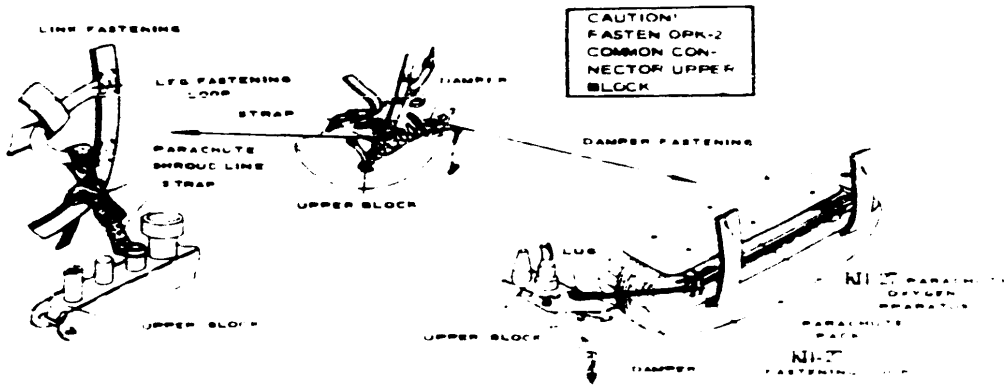

FIG 39 OPK 2 COMMON CONNECTOR UPPER BLOCK FASTENING

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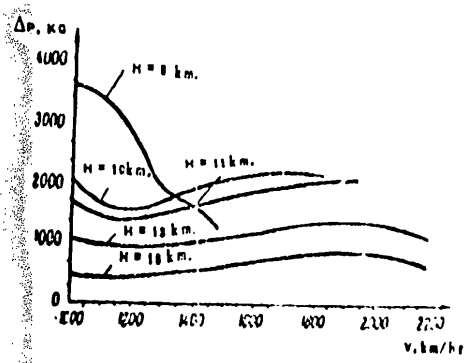

FIG. 40. МиГ-21ф-13 AIRCRAFT SURPLUS THRUST VARIATION ACCORDING TO FLYING SPEED AND ALTITUDE

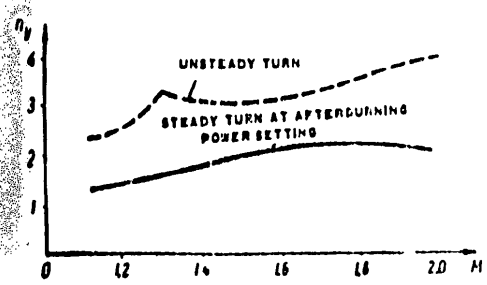

FIG. 41. G-LOAD LIMITATIONS IN TURN IN STRATOSPHERIC FLIGHT (H = 15,000 m.)

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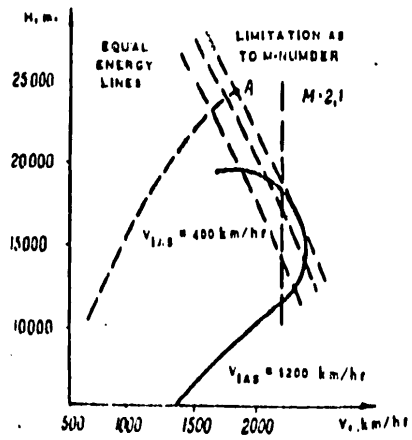

FIG. 42. VARIATION OF [illegible]-21ф-13 AIRCRAFT ENERGY LEVEL ACCORDING TO M-NUMBER AND DYNAMIC ALTITUDE ZONE(POINT A IS DYNAMIC CEILING WHEN IAS AT ZOOM IS DECREASED TO 400 km/hr)

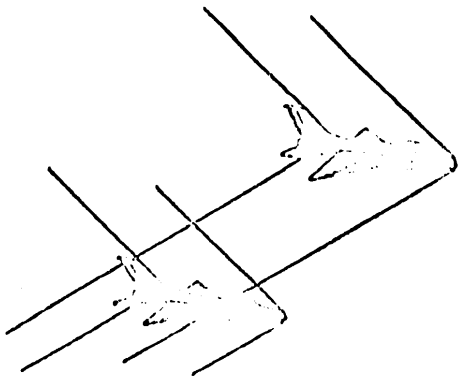

FIG. 43. SHOCK WAVE [illegible] PAIRS FLYING ECHELON FORMATION

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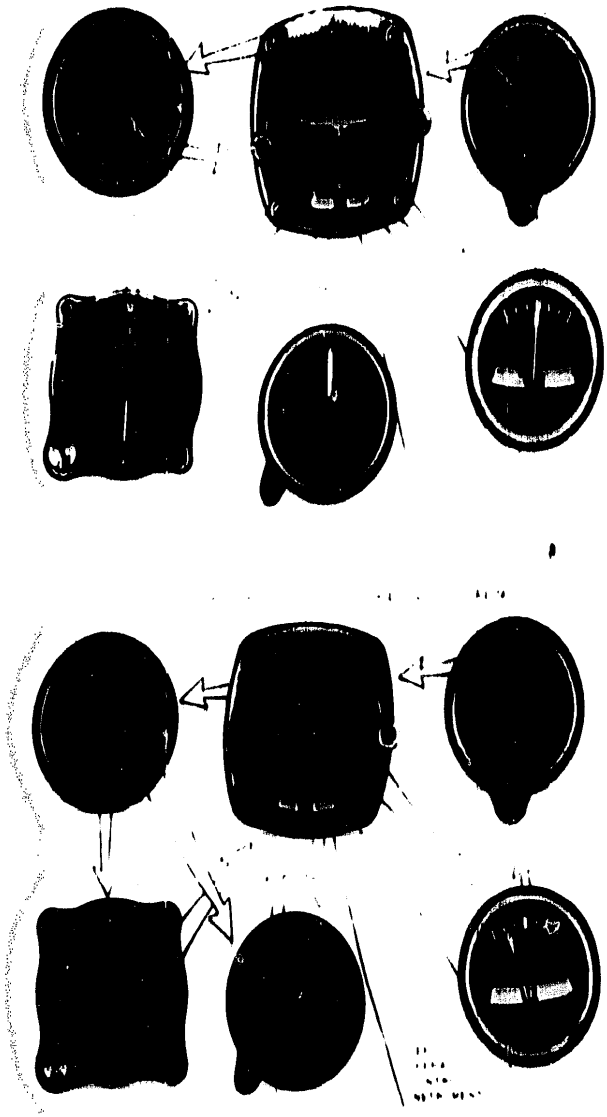

FIG. 48. DIAGRAM OF ATTENTION DISTRIBUTION [illegible]

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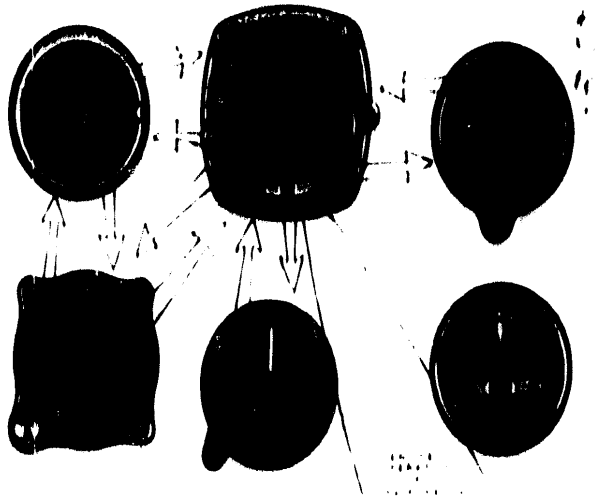

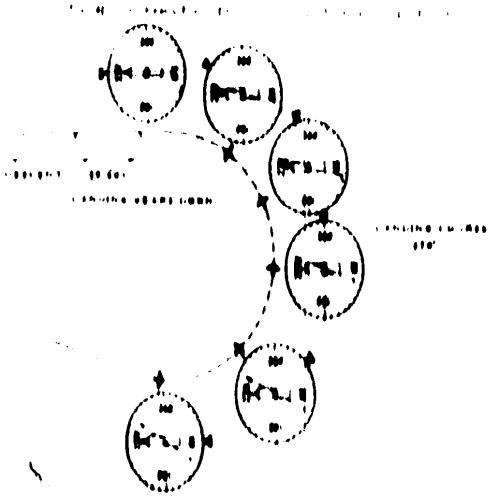

FIG. 47 [illegible] GYRO INDUCTION COMPASS READING WHEN AIRCRAFT TURNS TO INTERCEPT LANDING COURSE

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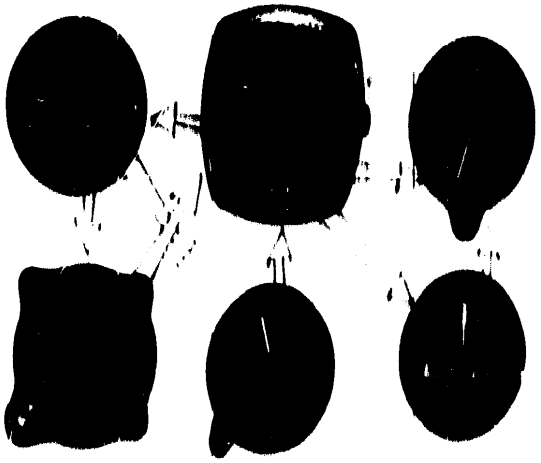

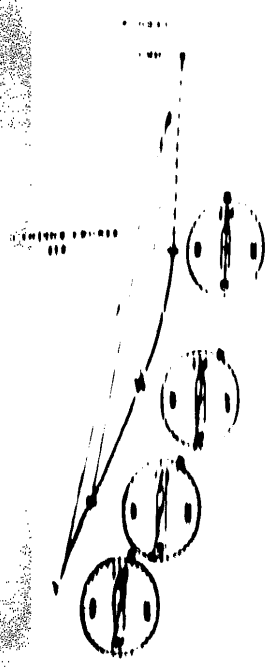

FIG. 00. RECTIFICATION OF LANDING COURSE BEACH

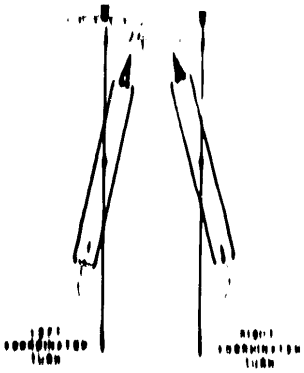

FIG. 00 DETERMINATION OF AIR CRAFT ATTITUDE RELATIVE TO RUNWAY BY MEANS OF APR COMPASS POINTER

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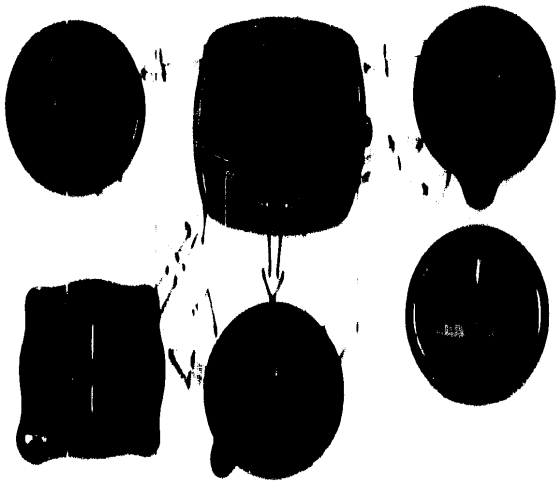

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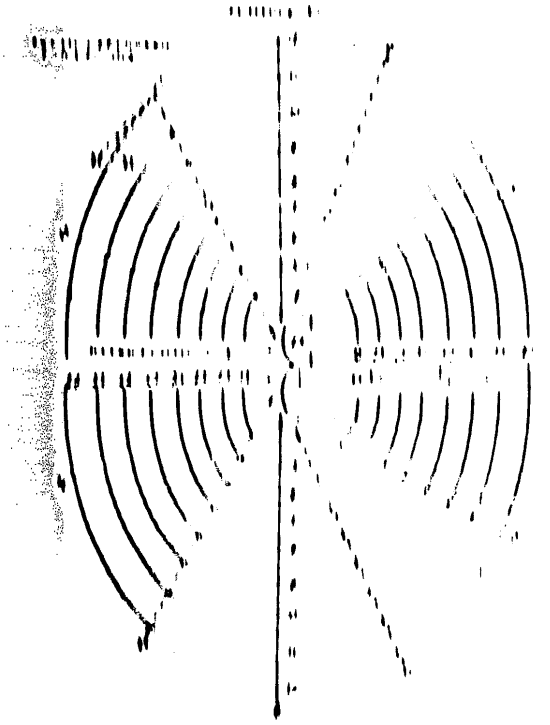

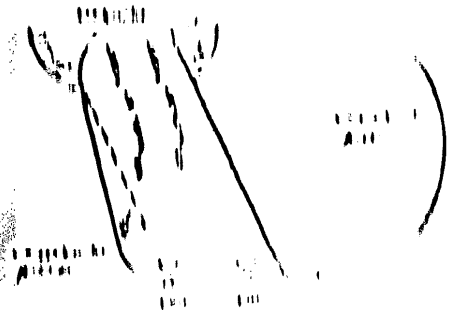

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